



UNDERSTANDING IRRIGATION DECISIONS

FROM ENTERPRISE PLANNING TO THE PADDOCK

Kelvin Montagu, Ben Thomas, Geoff Thomas,
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Kelvin Montagu, CRC Irrigation Futures
Ben Thomas, Scholefield Robinson Horticultural Services Pty Ltd
Geoff Thomas, Thomas Project Services
Evan Christen, CSIRO, CRC for Irrigation Futures
John Hornbuckle, CSIRO, CRC for Irrigation Futures
Craig Baillie, CRC for Irrigation Futures
Chris Linehan, Department of Primary Industries, Victoria
Peter Smith, NSW Department of Primary Industries, CRC for Irrigation Futures
Fabian Gallo, HydroTech Monitoring Pty Ltd
Sam North, NSW Department of Primary Industries, CRC for Irrigation Futures
Wayne Meyer, CSIRO, CRC for Irrigation Futures
Richard Stirzaker, CSIRO, CRC for Irrigation Futures
Peter Cornish, University of Western Sydney, CRC for Irrigation Futures





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Postal address: GPO Box 2182
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Office Location: L1, The Phoenix Building
86 Northbourne Ave
Braddon ACT

Telephone: 02 6263 6000
Facsimile: 02 6263 6099
Email: Land&WaterAustralia@lwa.gov.au
Internet: www.lwa.gov.au

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Preface

This publication combines the experiences and insights of irrigation consultants and extension officers with that of social, agronomic and engineering scientists. The resultant publication is targeted at those who advise, support and supply irrigation dependent enterprises with new information, tools and equipment.

We have purposely defined irrigation decisions in their broadest context. This is based on the authors' experiences who collectively have observed many failures when irrigation decisions are not placed in the context of the irrigation enterprise.

In bringing together contributors across a wide range of disciplines and backgrounds, we commenced by agreeing on the following key principles:

- Irrigation is a business
- Irrigation decisions are made right across the enterprise - at planning (strategic) and management (tactical) levels
- Irrigation enables enterprises and communities to exist in regions where otherwise there would be none
- Irrigation is but one input. To improve irrigation practice we must ensure that irrigation decisions are integrated into the enterprise.
- Irrigation can be a powerful crop management tool. Correct irrigation decisions can have a major impact on crop yield, quality and profitability
- Production and business sustainability are the big drivers of adoption of new information, tools and equipment
- Irrigation decisions are made by people.

By providing the context in which irrigation decisions are made the potential value of innovations are increased. Placing information, tools and equipment appropriately into the irrigation enterprise's existing system increases the likelihood of successful business, productivity and environmental outcomes.



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1 Introduction

Irrigation is a business activity. In the Murray and Murrumbidgee basins alone, on- and off-farm investment in irrigation infrastructure has asset values of \$6.3 and \$3.8 billion, respectively. Irrigation businesses also have a total water asset potential worth more than \$6.6 billion (2001 values; Meyer, 2005). Irrigation decisions impact on how these assets are managed, both strategically and operationally, and the returns they generate.

Irrigation generates a disproportionate amount of total agricultural profit. The National Land and Water Resources Audit estimated that irrigated agriculture, while accounting for only 0.5% of the total agricultural area, generated 51% of the total agricultural profit for the five year period to 1996/97. Within the Murray-Darling Basin irrigated agriculture, utilising 1.4% of the total land area, accounted for 36% of the total profits generated by agriculture in 2000/01 (Bryan and Marvanek, 2004).

Irrigation decisions are made at all levels of the irrigation business. From purchasing or redeveloping an existing property, trading water, selecting crops and cropping systems, to determining when and how much water to apply, decisions on irrigation are required. Furthermore, irrigation decisions are but one input in the irrigation enterprise. But these irrigation decisions are both an enabler and powerful management tool within the irrigation enterprise.

Irrigation decisions are made within a wider context. Both in Australia and around the world economic pressures on farms, increasing competition for water and increasing recognition of the environmental impacts of irrigation on rivers, groundwater and dependent ecosystems all impact on the irrigation decision (English *et al.*, 2002).

Above all irrigation decisions are made by people. As such the personalities, goals and aspirations of the individuals, the businesses they run and the communities in which they live have a major impact on irrigation decisions.

1.1 Understand Irrigation Decisions – structure and case studies

Understanding Irrigation Decisions has been written to put in content and provide guidance on irrigation decisions ranging *from enterprise planning to the paddock*. To understand the breadth of irrigation decisions requires consideration of the social, financial, agronomic and engineering aspects – a challenging task. *Understanding Irrigation Decisions* has combined this breadth into one document.



Chapter Two outlines the broad context in which irrigation decisions are made – environmental, social, technical and financial. This chapter challenges the reader to consider what makes the whole system work. The objective is to increase the likelihood of irrigation decisions producing successful business, lifestyle, productivity and environmental outcomes.

Chapter Three explores how irrigation decisions involving change and/or the adoption of new information, tools or equipment can be derailed if the decision is not put in context.

Chapter Four gets into the ‘big picture’ irrigation decisions. This is where lifestyle, banks and markets set the direction of the irrigation enterprise for the next one to five years. Frequently these decisions are not given the priority they deserve.

Chapter Five jumps into the field and the technical details of irrigation decisions made during a season. This is where considerable benefits can be delivered if sound technical irrigation decisions are made. Realising these benefits will require those that support, advise and supply irrigation dependent businesses to take into consideration the context outlined in Chapters Two to Four.

Chapter Six looks at how irrigation decisions might make use of technology to tap into the increasing wave of information available for irrigation decisions.

In this publication case studies from a range of irrigation businesses are used to highlight the decision making framework and the information used to make irrigation decisions. These case studies are introduced below.

1.1.1 Mike Logan – surface irrigated cotton

Mike views himself as a dryland farmer who irrigates to supplement the frequent summer storm rain. His property is in the Narrabri district, NSW and receives on average 650 mm of rain per year. Mike’s main crop is cotton with rotation and opportunity cropping of wheat, sunflower and soybean. Water for irrigation is drawn from both the Namoi River and groundwater.

Mike has worked hard to optimise his furrow irrigation system. He has had application performance evaluations undertaken by a consultant using Irrimate™, EM and slope surveys. This, combined with GPS yield monitoring, is used to constantly evolve the layout and operation of his farm.

1.1.2 Allan Goode – overhead irrigation of cotton

Allan has managed Little Mollee, a cotton seed production farm west of Narrabri, for over 20 years. Allan draws his water mainly from the groundwater with some water also obtained from the Namoi River.



Little Mollee is one of the pioneers of the use of overhead irrigation machines in cotton. Allan currently manages one lateral move and several centre pivots. Being a pioneer, Allan has had to learn how to integrate the overhead irrigation systems into the running of the property largely from his own experience.

1.1.3 Don Barwick – sub-surface drip irrigated lucerne

Don owns a small property east of Tamworth, NSW. In addition to running an engineering business, Don irrigates 12 ha of lucerne using sub-surface irrigation. Don installed the sub-surface irrigation system himself in 2003 after being a slave to a hand-shift sprinkler system. Apart from reducing the physical effort required, Don knew that sub-surface irrigation was also more water efficient. His water is drawn from the groundwater, which during the drought has fallen, highlighting the need to make the most of his available water. Don continues to irrigate a further 25 ha of lucerne using hand-shift sprinklers, reluctantly.

1.1.4 Angelo Tatti – overhead irrigated peanuts

Angelo Tatti runs an 80 ha property in Mutchilba approximately 115 km west of Cairns, Far North Queensland. The area receives an average of 600 mm of rain per year. Angelo grows 1600 avocado trees and 20 ha of peanuts and accesses water from Mareeba-Dimbulah Supply Scheme managed by Sunwater. Angelo has been farming the property for 18 years. Overall Angelo has decreased his crop area to match crop water demand and availability thus becoming more efficient with his irrigation scheduling, maximising his profitability and productivity.

1.1.5 Bruce Nastasi – micro-sprinkler irrigated mangoes and limes

Bruce Nastasi farms a 60 ha property area approximately 100 km west of Cairns, Far North Queensland. The Mareeba-Dimbulah area relies on irrigation as the average rainfall is 400-600 mm/year. Water is supplied via a channel system by the Mareeba-Dimbulah Supply Scheme managed by Sunwater. Crops grown on the property are mangoes (8000) and limes (1000). Bruce is one of the pioneers that instigated the Mango industry in the Mareeba-Dimbulah area and has been growing mangoes for over 30 years. Since 2004 Bruce has exceeded his previous production levels in both mango and lime crops due to irrigation scheduling.

1.1.6 Paul Ferraro – overhead irrigated potatoes

Paul Ferraro has a 263 ha property in Tolga, 90 km south-west of Cairns on the Atherton Tablelands, in Far North Queensland. Crops grown on the property are 65 ha of fresh market potatoes, 80 ha of peanuts with rotation crops being 80 ha of grass seed and 80 ha of corn. Average rainfall (for the Atherton Tablelands) is approximately 1200 mm, 80% falling between February and April. Paul accesses water supplies on the property via under ground bores. Paul made the change



from a high pressure gun irrigator (self-propelled) to a low-pressure lateral move irrigation system in 2001 and currently owns three low pressure lateral move systems. Making changes to his irrigation systems has allowed him to improve his profitability and sustainability.

1.1.7 Joe – strategic irrigation business planning

Joe is a wine grape grower based in the Riverland of South Australia. His 50 hectare property was previously used to grow citrus but Joe, like so many others, decided to increase his borrowings to remove the citrus and plant wine grapes when demand for grapes was high. Given the downturn in the wine industry along with the fact he has lost his grape supply contract with the local winery, Joe is looking at removing the grapes and planting another irrigated crop.

NB Joe is a fictitious case study that draws on many real examples. Experiences have been combined into a generic case study to respect the privacy of the individuals.

1.1.8 Reducing drainage losses

Peter manages a 50 ha vineyard in the Murrumbidgee Irrigation Area, NSW using surface irrigation. The existing irrigation practice relied on scheduling by ‘gut feeling’ and irrigation application by broad-based furrows that wetted the entire floor area of the vineyard. The vineyard had a subsurface drainage system (tile drainage) connected to a main sump. The vineyard was intensively monitored from January to May for the 1996/97 season under the farmer’s routine practices.

In the following season changes were made to the irrigation and drainage management. Wide furrow was replaced by narrow furrows and irrigations were scheduled with tensiometers (re-irrigating at about 80kPa, after flowering).

1.1.9 Jim - system change and on-farm operational trials

Jim is a farmer in the Sydney Basin. He wanted to try drip irrigation to see if the benefits were as great as people claimed. Jim set up an operational trial comparing his existing lateral shift sprinklers system to a drip system growing Sebago potatoes. The drip irrigation system supplier provided advice, but the farmer managed the trial. Jim also got some researchers involved to measure soil water (Enviroscans and tensiometers), drainage, runoff and yield.

1.1.10 Rob Cooper – centre pivot irrigated dairy pasture

Rob manages a 1400 ha dairy farm, of which 250 ha is irrigated, at Upper Manilla, NSW. Rob runs 800 milking cows, producing around 7 million litres of milk a year, 500 young stock and employs seven staff. Recently several travelling irrigators were replaced with 8 centre pivots varying from 10 to 73 ha. Because the centre pivots don’t have to be moved, irrigation is done much more on time. He aims to run all of them for some time each weekend. His decision on how much to apply is based primarily on long-term average evaporation rates and

observation of the pasture and soil. The grazing rotation is also a major factor if rain is forecast – he will hold off irrigating if stock are to be in a paddock to avoid pugging of the pasture.

Throughout the text experiences from these growers are included to illustrate how irrigation decisions have been made.





2 Establishing the Context for Irrigation Decisions

In order to remain profitable in increasingly competitive local and global markets, Australian farmers have to operate a farming system that involves management of natural resources, people, plants and animals with the inputs of feed, fuel, fertiliser, chemicals, water, management skills, finances and time. A key to successful farming is to ensure predictable outcomes from as many of these inputs as possible and thereby ensure profits are generated at acceptable levels of risk.

The farming environment is constantly changing as a result of internal and external factors. In common with most change, decisions in irrigation enterprises involve consideration of a very complex array of on- and off-farm factors such as changes in family circumstances, fluctuations in market prices, variations in climatic conditions and changes in government policies to name just a few. Irrigation practice itself is just one of the many technical, personal, social and environmental factors in this mix.

Experience and research show that decision-making is rarely limited by a lack of technical information or dominated solely (or even mainly in many cases) by the profit motive *per se*. Consequently, the integration of a new practice or technology into an existing farming system requires careful planning and management. The greatest challenge is to understand how the system works so as to put all the decision-making drivers together.

Integrating irrigation decisions into the enterprise

All these irrigation improvements, along with other improvements on the dairy enterprise, allow Rob to grow pasture better suited to the cows rather than the logistics of the irrigation. Irrigation is now as high a priority in the work rosters as milking – and Rob takes pride in keeping up his irrigation schedule 90% of the time.

Case study 1.1.10

How these drivers fit together will depend to a large degree on the stage and scale of change. Is the enterprise a new start-up, an expansion or change in irrigation enterprise, or a change in practice to improve irrigation efficiency? Similarly, does the prime enterprise mix involve annual cropping, pasture for livestock or is it perennial horticulture?

The use of irrigation has a number of attractions for producers:

- Compared with rain fed systems, it provides a flexibility and capacity to generate profit and better manage risk
- It can provide greater management options and sustainability for the enterprise(s)
- It provides a capacity to manipulate the crop in terms of the level of production, timing and quality.



A good example of using irrigation to manipulate the crop comes from the grape industry, where irrigation timing has a major impact on yield and berry characteristics for wine. In the current industry situation of surplus supply/low prices, some growers are reducing irrigation as part of their loss minimisation risk management strategy.

Whilst irrigation provides greater opportunity and reduces risk, it also leads to a more complex decision making environment. Furthermore, each decision environment is different and information driven, ‘one-size-fits-all’ approaches are rarely successful, and yet they still seem to form the basis of many extension programs.

Decision making is not just about data sets or models. It is about understanding the array of factors and integrating them into a systems approach to meet the goals of the operator. That is the role and challenge facing the field consultant.

2.1 The Decision Making Drivers

The main drivers fall into three broad categories:

- Environmental
- Social/Personal
- Technical/Financial

These drivers commonly represent what has become popularly known as the ‘triple bottom line’ approach to management which has been adapted to irrigation enterprises (Shepherd *et al.*, 2006).

These drivers are all related but it is important to consider each in turn. The relative importance of the drivers will depend on the goals of the operator. Since much of the remainder of this publication deals with technical and financial drivers, environment and social drivers are dealt with first.

2.1.1 Environmental drivers

As irrigation systems move from a development to a management phase, on- and off-farm natural resource management practices have become increasingly important. It is clear that irrigation has had a significant impact on the natural resource base. On the land, native vegetation has been removed, wetlands drained or flooded, earth moved and drainage lines changed and soils cultivated. The extensive clearing and subsequent addition of large volumes of water through irrigation has caused a fundamental change in groundwater distribution. In the rivers, flow patterns and volumes are very different with return of drainage waters contributing nutrients, salts and chemicals (Meyer and Noble, 1993).

Irrigation businesses are under increasing pressure to manage these impacts. Government, regional and industry organisations are



employing a range of instruments to exert pressure on growers to implement on and off-farm practices which produce beneficial natural resource management outcomes. These efforts are supported by the shift within society to a more environmentally friendly paradigm largely brought about by the increased insight into environmental degradation (Lyle and Ostendorf, 2005).

Nowhere is this more obvious than with water, where legislation now governs its use, not only in terms of volume, but also in terms of maintaining the quality of the asset. For example, the pressure is on irrigators of all types in the Murray Darling Basin to improve irrigation practices, not only to improve the efficiency of water use on-farm and reduce the deleterious effects of drainage, but also to save water to create environmental flows for the benefit of the whole system.

The Living Murray program aims to deliver environmental benefits to six icon sites along the Murray River by maintaining the healthy aspects of these sites and beginning to address the decline in other areas as part of a larger effort to establish a healthy working river (Murray-Darling Basin Commission, 2005). Central to this program is the recovery of water through infrastructure improvements and rationalisation, on-farm initiatives, efficiency gains, and market based approaches including the purchase of water from willing sellers.

Environmental impacts on irrigation decisions

Joe is concerned about the state of the Murray River and is an active member of the local Landcare group. He would like to see improvements in salinity and sediment management. Joe has spent considerable time and effort reducing soil salinity, limiting erosion and preventing weed infestation on his property. He would not like to see this effort wasted if he sells the property.

Case Study 1.1.7

Another example of environmental issues driving irrigation enterprise decisions is the influx of hobby farmers in many farming areas. Not only do these hobby farmers object to many traditional practices, such as the use of chemicals, but they question how traditional farmers use the resources, especially water. These issues are at the core of the 'Right to Farm' debate.

Whilst most farmers now appreciate the need to be responsible in their use of water and the associated land, it is reasonable to expect a continuation of public pressure towards more efficient and responsible water use and its increasing transfer to uses which give the best return, some of which will be non-agricultural.

Similar considerations are likely to arise in future with regards to the relative energy requirements of enterprises which will impact on irrigation decisions, e.g. gravity vs. pressurised systems.



Environmental and financial drivers are linked. Economic factors including farm size, off-farm income and level of farm equity influence the likelihood of adoption of natural resource management practices (Nelson, 2004). Growers can not be green if they are in the red.

2.1.2 Social drivers

The social drivers in decision making are probably some of the most important but are often poorly understood and difficult to measure. There are normally two dimensions – community and personal.

2.1.2.1 Community

In terms of community, it is generally accepted that one of the basic human needs is to be accepted by their peers. People are therefore unlikely to engage in behaviours that result in criticism including such things as poor irrigation practices. Peer pressure of course can also hamper beneficial change, which is one of the reasons why more progressive farmers often form groups outside of, as well as within, their local area.

Being part of the group and contributing to the community and the services it provides has been a central part of the development of rural areas, and people will strive to retain that. An example of this is in major rural adjustment programs where rationalisation, albeit economically sensible (and probably inevitable), is resisted because it will weaken the very fabric of the community and the services it provides to them and the next generation. The conflict is obvious. On the one hand there is the need for individuals to expand their operations by buying out their neighbour, but this comes at the expense of the community. A case in point has been the dairy industry which went through rationalisation following market deregulation.

In advocating change, therefore, it is always important to understand local community attitudes. Adjustment programs frequently miss this aspect and believe that simply providing financial incentives can drive change.

2.1.2.2 Personal and family

Personal and family considerations are important because they usually provide the basis of an individual's goals in life and determine their comfort zone. There are many things to consider including:

- age
- desired work/leisure balance
- stability of the family unit
- importance placed on material wealth
- the desire to be seen as a leader
- family requirements, now and in future
- succession issues



- availability of labour
- capacity to grasp and adopt new information
- financial history
- current financial position and attitude to risk.

Personal and social impacts on strategic irrigation decisions

Joe is 58 years old. He requires long term financial security. He has little desire to move into a completely new crop area. Born and bred in the Riverland, Joe has no desire to move and wants to remain active in his community.

Joe's son is currently employed in the local town as a local agricultural chemical retailer. He has made some indications that he would like to eventually return to the family property.

Joe and his wife Doris would like to travel. Joe also enjoys golf and fishing and would like more time to engage in these activities. Joe is strongly independent. He is not comfortable working for others and prefers not to deal with larger corporations given his experience with wine grapes.

Joe's daughter also lives in the local town with her two children whom Joe and Doris visit on a regular basis. Doris also looks after the grandchildren 3 days a week to allow their daughter to work.

Case Study 1.1.7

People and the irrigation decision

Sometimes Mike allows adjustments to his irrigation decisions on weekends by giving family responsibilities a higher priority.

Christmas time always creates a disruption to the usual pattern as staff concerns take priority over irrigation timing. The field staff want 2-3 days off over this period. This usually results in a silly decision being made – such as irrigating too early or too late. The importance of having happy staff is recognised by Mike and he willingly allows the trade-off of a setback to the crop for this.

Case Study 1.1.1

2.1.2.3 Risk

The significance of risk aversion to irrigation decisions has been demonstrated by English and Orlob (1978). They reported that the most risk-averse manager would prefer an irrigation strategy with a 40% lower expected profit than preferred by most risk-tolerant managers. In short, risk-averse irrigators would tend to use more water per unit of land.



2.1.3 Technical and financial drivers

There is a plethora of technical information, the relevance of which depends on the enterprise and circumstance.

Here is an overview of some of the information that should be considered. It uses an orchard as an example but the same principles apply to other enterprises.

- *Past history (if new development)*
 - cropping history, including notable successes or failures or important pest and disease considerations?
 - irrigation system infrastructure
- *Soils*
 - soil survey (report, maps, suitability for enterprise)
 - surface soil tests and recommended fertiliser and soil amendment applications
 - proposed method of soil preparation and treatment prior to planting/installation

Technical constraints to irrigation decisions

Land and climate is suitable for most crop options available to Joe. Irrigation equipment and his plan are flexible and could be adapted for most crop types. The availability of skilled labour is short and Joe would probably need to continue to manage the property and may end up doing most of the work. No significant encumbrances to production exist.

Case Study 1.1.7

- *Climate*
 - regional climatic data (temperatures, rainfall, frosts, etc.)
 - suitability of climate for proposed enterprise
- *Irrigation*
 - current water licences
 - availability/costs of extra water
 - capacity of existing channels/pipelines/pumps to deliver volumes of water required
 - need for on-farm storage
 - irrigation system specifications (drippers, sprinkler, outputs, spacings, etc.)
- *Drainage*
 - regional hydrology and drainage issues
 - access to surface drainage scheme
 - on-site drainage hazards
- *Planning and agency requirements*
 - requirement for “Irrigation and Drainage Management Plan” (IDMP) or other state equivalent as part of development, or transfer of water
 - possible local environmental issues (native vegetation, water management, deal with drainage on property etc.)
- *Orchard*



- existing/proposed layout (row spacing, tree/vine spacing, row direction, headlands, etc.)
- development plan
- management plan (post-development)
- production schedule of yield by age
- yield at maturity
- development budget and operating budget
- *Time table for change*
 - what is to be done by whom, when? – in detail
- *Financial (see also Planning for change section below)*
 - overall budget including that for the change as well as the rest of the enterprise and personal requirements
 - capital requirements
 - capital availability/costs/repayment terms
 - cash flow/peak debt etc. from the budget
 - financial options in terms of scaling-up the investment
 - securing the loan
 - contractual arrangements/succession planning

Financial Drivers

Joe has limited finances due to large debts incurred following his change to wine grapes and therefore would need immediate cash flow with any new crop. Despite this, Joe is able to borrow funds. However this is tempered by Joe's desire at his age for financial security and to maintain control of his property and destiny.

Joe is a good grower who uses consultants when required. His current predicament is largely due to external market forces. Joe holds a water licence for 250 ML. Currently water can be 'sold' for \$50 per ML (temporary trade) or \$1,500 per ML (permanent trade).

Joe has had offers from an environmental group to convert the property into an environmental reserve.

Case Study 1.1.7

- *Labour/Management*
 - does the current manager have the technical and financial capability to manage the change?
 - skills/labour requirements for the different phases of development
 - proposed management structure (job descriptions)



3 Irrigation Decisions, Change and Barriers

Irrigation decisions often involve change due to new information, tools or equipment. For example, moving from a surface irrigation system to a low pressure overhead system. Such decisions are influenced broadly by technical, social and environmental drivers outlined above. Furthermore, the process of adoption of new technology has its specific challenges.

3.1 Adoption of irrigation tools and practices

The process of adopting any technology has four steps (Rogers, 1983):

- **Awareness** (of the opportunity/need)
- **Information**
- **Trial**
- **Adoption**

For adoption to occur, farmers need to move through this adoption process. In reality, whilst many may be aware of the opportunity and /or need for technology, fewer seek more information, fewer still trial the change and even fewer adopt the change.

A key to understanding whether or not a change will be adopted (be it related to irrigation or other practice) is based on its relative advantage over and, its compatibility with, current farming practices (Rogers, 1983 and Kaine *et al.*, 2005). Relative advantage and compatibility are usually strongly related since the benefits of adopting a new practice depend heavily on the ease with which it can be integrated into the existing mix of practices and techniques used in the farm enterprise.

The adoption of most technologies that aim to alter farm management can be likened to the purchase of a 'high involvement product' (Kaine, 2004). High involvement products are described by Assael (1998) as generally being expensive, rarely or infrequently purchased and tied to self-image and ego. They usually involve some form of risk, such as financial risk or risk to self-esteem. Where the risks are high the farmer is more likely to devote time and effort to careful consideration of alternatives before making a purchase.

Viewing the adoption of new practices as a form of high involvement purchasing raises a number of issues. First, it implies that farmers are active seekers of information and are likely to devote a substantial amount of time and energy to evaluating new practices they see as offering a potential benefit. Changes in irrigation enterprises or practices are normally complex and intellectually demanding, and usually involve large investments. As such, the information search and adoption process may take place over a long period (Kaine and Niall, 2001). Increasing this complexity is that these decisions are often made against a background of uncertainties such as markets and water allocations. These cumulative uncertainties reduce the adoption of new



technologies due to the uncertainty of returns, which effectively increases the return threshold required before investments are made (Hafi *et al.*, 2006).

Second, this view implies farmers are unlikely to retain apparently outdated or inefficient practices simply on the grounds of ignorance, tradition or conservatism. Third, this view implies that the decision not to adopt a new practice will be founded on a reasoned argument. Attempts to promote adoption that do not address these three arguments are likely to meet with limited, if any, success.

The benefits of irrigation scheduling?

Don is reasonably happy with the performance of his irrigation system, and considers he has the scheduling about right as production has increased to around 1900 bales (48 tonne) per cut from 30 acres (12 ha) or 24 t/ha. However, he is concerned that he may be over-watering and not know it. He has thought about installing soil water monitoring equipment but has not gotten around to it yet. One reason is that he would prefer to have a better idea of the potential benefit before doing so.

Case Study 1.1.3

Using the adoption path outlined by Rogers (1983) combined with the work of Kaine *et al.*, (2005), some comments on the likely barriers to adoption are made below:

- **Does the innovation provide a greater relative advantage and is it compatible with current farming methods?**

For example, some new irrigation practices may lead to higher quality products but if the innovation requires greater time and labour to use it then real benefits may be seen as coming at too high a personal or financial cost.

Matching cultivation system to irrigation system

Allan quickly learned that the traditional approach of planting cotton on hills one metre apart was not good for overhead irrigation machines, especially on lighter red soils. The water ran off the hills away from the plants and into the wheel tracks resulting in an uneven crop.

When Allan installed another new centre pivot, he planted into flat ground, still at one metre spacing, resulting in better water penetration and better yield. He has now flattened the hills in the original field, immediately seeing an improvement.

Case Study 1.1.2

- **Can the innovation be adopted?**

There are examples where an innovation may provide relative advantage and be compatible with farming practices but cannot be adopted. For example unless the irrigation infrastructure allows irrigation on demand, the benefits of micro-irrigation or sophisticated irrigation scheduling practices will be minimal.



- **Complexity of the innovation.**
The complexity of an innovation is likely to be a substantial barrier to adoption (Vanclay and Lawrence, 1994). As described earlier, changes in irrigation enterprises or practices are normally complex and intellectually demanding and involve large investments over the long term. Decisions are also made against a background of uncertainties such as markets and water allocation and security.
- **Can the innovation be easily trialled?**
The ability to trial an innovation is important to adoption. Changes that can be trialled on smaller areas are more likely to be adopted (Vanclay and Lawrence, 1994). This allows the farmer to determine the likely result on their property without exposing themselves to excessive risk.

Similarly, innovations that can be partially adopted, rather than an all or nothing approach may have greater adoption rates. For example, GPS has created many options for farmers but a farmer does not have to adopt all the features that having a GPS system can offer to take advantage of the innovation. In the case of many irrigation systems it is frequently difficult to gradually scale-up the adoption of changes which adds to the risk (Rogers, 1983).

Learning through on-farm operational trials

Jim trialled a new drip system against his existing lateral shift system. The water equation looked impressive for the drip system - about half the water applied, wetter soil to a greater depth, and less runoff and the associated environmental costs. Unfortunately, Jim did not recognise that water was running low in the trickle block during tuber development which is a critical period for potatoes. Tensiometers were installed in the trial, but the farmer lacked confidence and experience in their use and did not act. The result was reduced yield and a discouraging experience. Next year Jim came back for more, but this time monitored the soil water with a tensiometer and enjoyed the full benefit the drip system offered.

Case study 1.1.9

3.2 Adoption of irrigation scheduling methods

Australian scientists have been in the forefront of research into the measurement of soil water, the fundamental processes that drive the flow of water through soils and uptake by plant roots. Australian companies have turned much of this knowledge into commercial products, which are sold around the world. Over the last decade, tens of millions of dollars have been spent by state agencies to get these products more widely understood and used by irrigators. Given this concerted effort what adoption has there been of objective irrigation scheduling tools?



Irrigation scheduling questions in the agricultural census provide good statistics on the use of soil water monitoring products by farmers. In 1996 13% of irrigators used soil water monitoring products, and this had increased to 22% by 2003 (Table 1). Whereas the increase in adoption rates is heartening, it is sobering to realise that almost four out of every five farmers who derive their living from using water do not measure how much water is in their soil. Moreover, the most recent statistics show that only 9% of growers plan future investment in soil water monitoring equipment.

Table 1. The percentage of irrigation scheduling methods used in Australian irrigation enterprises based on 1996, 2001 and 2003 Agricultural Census.

Irrigation scheduling method	1996	2001	2003
		%	
Tensiometers		8	9
Soil probes ^a	13 ^b	8	13
Government/commercial scheduling service		2	3
Evaporation figures/graphs		7	10
Calendar/rotational scheduling	14 ^c	12	13
Local knowledge/observation	93	81	91
Other methods	-	6	4
Total ^d	120	124	143

^aneutron and capacitance probes.

^bThe 1996 census grouped tensiometers, soil probes and scheduling services together.

^cThe 1996 census grouped Evaporation figures/graphs and calendar/rotational scheduling together.

^dThe data adds to more than 100% because multiple answers were permitted.

There are considerable differences across commodities in the adoption of objective scheduling techniques (Figure 1). There are only three commodities in which a scientific method of scheduling had been adopted by 10% or more of irrigators. These include tensiometers in the fruit/nut industry, tensiometers and soil probes in the grape industry and soil probes in the cotton industry (Figure 1). Evaporation figures are the most common method for the rice, sugar, cereal and pasture industries but still attract less than 10% of growers.

Such statistics are alarming. Tensiometers are a proven, economical and accurate method, which have been widely available for over four decades. They have been consistently promoted by agencies and extension workers, but the adoption rate has stagnated below 10% for many irrigated commodities. A similar case can be made for the use of evaporation figures and models. What this experience indicates is that these sound techniques have not captured the hearts and minds of the target audience.



The one bright light is the soil probe category, which is now predominantly made up of logging or manual capacitance probes. Recent data shows the adoption curve is still rising. Adoption is likely to continue as the word spreads, the technology gets cheaper and reliability and confidence in using the equipment grows among irrigators.

Introducing new technologies

Over the past couple of seasons Rob has been trialling a soil moisture capacitance probe. He has found that it tells him three useful pieces of information: whether the soil profile is filling or emptying over several irrigations, how quickly the water is being used by the pasture, and an idea of the Readily Available Water status of the profile. This information helps him decide when and how much water to apply. The interval has varied from 3 days in the peak of summer to 7 days in the cooler months.

The probe information also gives him an indication of how effective a series of irrigations has been. His experience with one probe has prompted him to want to install more and ideally telemetry as well to avoid the labour time of having to go to the field and manually download data. However, though they are helpful, Rob insists that soil probes are not foolproof and won't rely solely on them – he still needs to use some 'feel'.

Case study 1.1.10

Moreover the revolution in communication technology may set off another wave of adoption as information can be collected and delivered cheaply to an office computer without all the hassle of downloading in the field.

However, the optimistic notions above must be tempered. Even for industries like cotton and grapes, where adoption is highest, two out of three growers have rejected the help of a tensiometer, soil probe, evaporation figures and consultant in 2001.

The size of the irrigation enterprise also has an influence on adoption of objective irrigation scheduling methods (Figure 1). In particular, the use of soil probes more than trebles as the size of vineyards increases. The influence of farm size is less pronounced in the cotton industry, but again shows that soil probes are more commonly used on large farms. There has been a distinct improvement in the adoption of irrigation scheduling tools between 2001 and 2003, no doubt due to the state-based water use efficiency programs. The 2003 census data provides a more progressive picture of the irrigation industry than the bald adoption of scheduling method statistics. Seven out of ten irrigators implemented changes to improve irrigation practice over the past 5 years – 46% made the application system more efficient, 37%



scheduled more efficiently and 15% invested in on-farm soil water monitoring (Table 2).

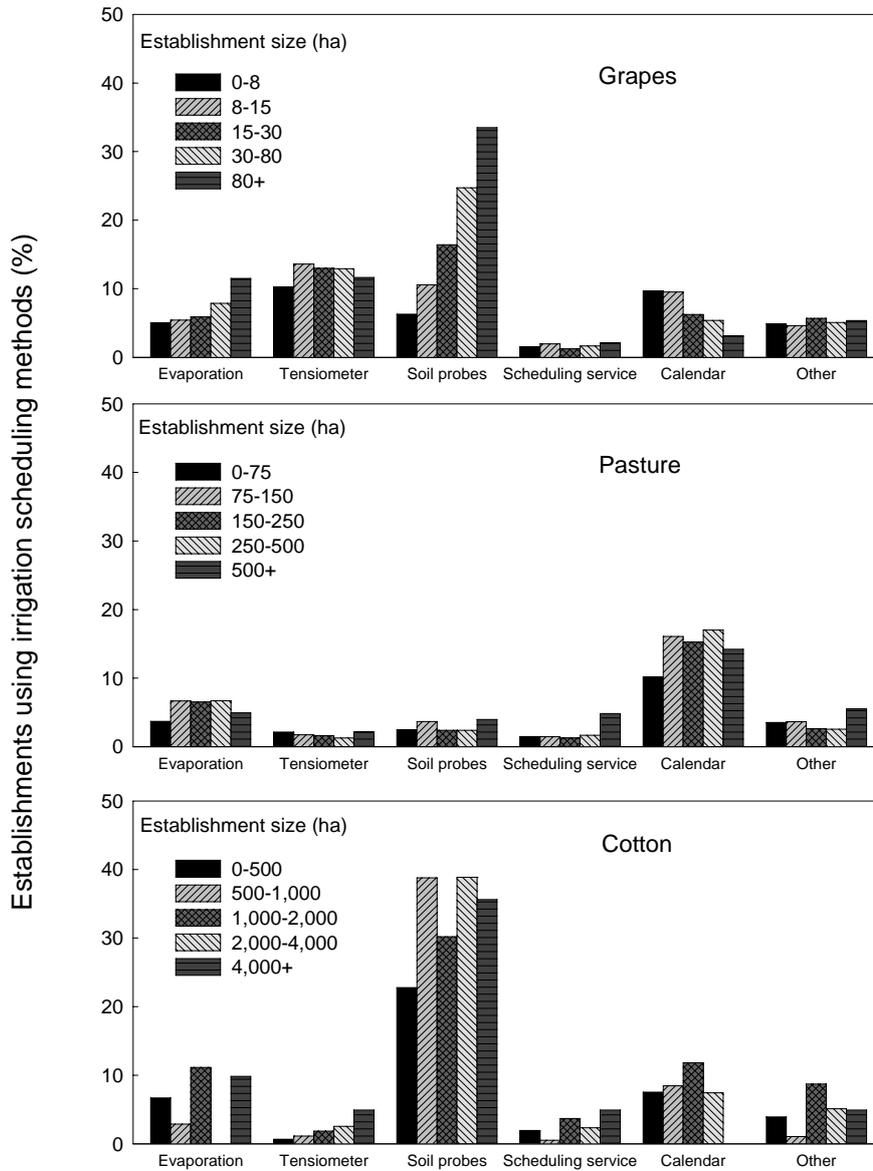


Figure 1. Percentage of irrigation businesses using objective irrigation scheduling methods.

The investment in soil water monitoring must include further investment by those already using the technology, as there is not a 15% increase in the percentage of irrigators using this technology. Furthermore, many farmers claim to have improved the efficiency of irrigation scheduling without investing in soil water monitoring (or other scientific methods). However, increasing irrigation efficiency comprises a diverse array of activities, including benchmarking activities, implementation of new equipment and on-going training.



Queensland Rural Water Use Efficiency Program reports give insight into the range of activities involved and the participation of growers¹.

Table 2. Percentage of irrigators who have made changes in irrigation practice, 1998 – 2003, and who intend to make changes in the future (ABS 2005).

	<i>Percentage change in irrigation practice</i>	
	1998-2003	Future
No change	30	56
One or more changes	70	44
<i>Type of change</i>		
More efficient application	46	22
More efficient scheduling	37	17
On-farm soil water monitoring	15	9

The future looks less promising. More than half the irrigators do not plan further changes in the foreseeable future, and only 9% think they will invest in soil water monitoring. This may indicate that a ceiling in adoption may be reached, or the figures may reflect ‘change fatigue’ following intensive government programs.

There are numerous barriers to implementing change (Stirzaker, 2006). The most important being lack of finance, uncertainty over water allocations and uncertainty over water availability (Table 3). It is interesting to note that only 8% of irrigators doubt that implementing change would provide successful results – this demonstrates faith in the available technology. If this is combined with the 12% who will not implement changes because of age or poor health, then 80% of irrigators would invest in better practices, should the barriers be overcome.

Table 3. Percentage of irrigators identifying barriers to changing irrigation practice (ABS 2005).

	Percentage of irrigators
No barriers	22
One or more barriers	78
<i>Type of barriers</i>	
Uncertainty over allocation	28
Inadequate water availability	26
Lack of finances	48
Lack of time or information	17
Age or poor health	12
Doubt about likely success	8

¹ See http://www.nrm.qld.gov.au/rwue/pdf/rwuei_program_eval_3.pdf for more information.



4 Irrigation Decisions and Enterprise Planning

4.1 Strategic Irrigation decisions in perennial enterprises

Strategic irrigation decisions are made when acquiring, developing or redeveloping an enterprise. Such irrigation decisions are influenced by the ‘big picture’ economic, environmental, social and technical drivers outlined in section 3. Whilst these decisions are made infrequently they often determine if the enterprise is successful in financial, family, social or environmental measures.

Jumping straight from the idea stage to the business plan is one of the common failings in planning for major enterprise or practice change. The result is often inadequate consideration of the above drivers, a half-baked proposal, and all too frequently, a failed venture.

There are three essential phases to proper planning for change, be it in an enterprise or a single practice.

4.1.1 Feasibility study

Will it fly?

The feasibility study includes a detailed look at personal goals and options, land/water options, crop options (including marketing options/outcomes), irrigation options, technical options, and financial options. What are the benefits and risks? Can the change be phased in or is it ‘all or nothing’. The feasibility study also considers the many environmental and legal limitations. It is the stage at which the consultant confronts the client with the tough issues.

Feasibility of an irrigation business

Joe’s age (and with it a lack of desire to restart from scratch), financial position and desire to remain on the family property are critical drivers in his decision. Mothballing the vineyard, replanting with citrus, replanting with pasture or selling the land and water and moving to the nearby town do not meet these criteria. As such these options are not feasible and are removed from the list.

Joe’s two remaining options – remove the grapes and grow potatoes or sell water and transform the property into an environmental reserve – meet most of his requirements and are both feasible options. Joe decides on potatoes as he is not yet ready to stop work and would like to leave his son with the option of returning to the family property.

Joe’s next step is to prepare a Business Plan for potatoes.

Case Study 1.1.7



4.1.2 Business plan

Yes, in theory it will fly, now how can it be designed to fly?

This is where the decisions are made on the preferred options. The business plan looks at capital, cash flow, peak debt and financial risks. It also looks in detail at other planning requirements such as the technical demands and risks, market opportunities and risks, and other requirements such as planning/environmental approvals.

Irrigation business plan

Having decided to remove the vines and grow potatoes, Joe needs to prepare a business plan. At this stage, Joe decides to use a consultant with experience in potatoes and business planning to ensure he covers all options and requirements. Preparing the business plan will include amongst other things:

- Establishing a market for the potatoes with the local processor.
- Costing the removal of vines.
- Determining whether to install pivot irrigators or go with permanent sprinklers. Can his existing irrigation system be modified to irrigate potatoes?
- Determining whether he requires irrigation monitoring equipment or whether he can reuse the system and equipment he had installed for the vineyard.
- Determining how much money he can borrow from the bank and whether he requires a repayment 'holiday' to enable the potato business to be established and cash flow generated.
- Determining whether he requires additional water. Alternatively, he may be able to sell some of his water licence to generate sufficient funds to minimise his loans.
- Determining whether it is more economical to purchase his own potato planter and harvester or to use contractors. In this respect, Joe may consider the option of performing contract work to supplement his income. This also provides additional options for his son to return to the family property.
- Determine target yields and income along with potential outlays on fertiliser, herbicides and pesticides.
- Determine whether it is more advantageous to adopt an organic approach.
- Determine skilled labour requirements. Can they be met?
- Can Joe access further land to lengthen his rotation and reduce the risk of disease buildup?

Case Study 1.1.7



4.1.3 Bankable documentation

Yes it will fly, now let's make it happen.

This phase sets out the detail of:

1. How the venture will be financed
2. The documentation required by the lender
3. The approvals required
4. The timetable for ordering and installation of supplies
5. Contracts,
6. Staff required and employment contracts, and
7. How progress will be monitored.

In short, it is the detailed plan of action and should include the timelines, milestones and who is responsible. This is not only necessary for the effective management of the change, but lenders are increasingly looking for this 'proof of capability'.

Irrigation business bankable document

Having prepared a business plan, Joe then needs to acquire bankable documentation such as contracts for produce, an independent review of the business plan, water licences, timetable for orders, quotes for removal of vines and installation of a pivot irrigator and costs of a planter and harvester to enable loans to be arranged. This case study clearly demonstrates that irrigation is just one decision making driver amongst many. Careful consideration of all the decision making drivers is critical to allow correct decisions to be made.

Case study 1.1.7



Summary of Joe's decision making drivers and possible options							
Decision making drivers	Mothball Vineyard	Citrus	Potatoes	Pasture	Sell water	Sell land and water	Move to town
<i>Personal/Social</i>							
Age	?	x	?	x	✓	✓	
Financial security	x	x	?	x	✓	✓	
Remain on property and in community	✓	✓	✓	✓	✓	x	
Options for son to return to the family property	✓	✓	✓	✓	?	x	
Time for travel, fishing, golf etc	✓	x	x	✓	✓	✓	
Proximity to grandchildren	✓	✓	✓	✓	✓	✓	
<i>Environmental</i>							
River health	✓	?	?	✓	✓	?	
Landcare	✓	?	?	?	✓	?	
<i>Financial</i>							
Needs immediate cash flow	x	x	✓	x	✓	✓	
Control of property and destiny	✓	✓	✓	✓	✓	x	
Environmental group	x	x	x	?	✓	x	
<i>Technical</i>							
Land and climate	✓	✓	✓	✓	✓	✓	
Skilled labour requirements	✓	x	x	✓	✓	✓	
New expertise required	✓	✓	?	x	x	✓	
✓ = Criteria met or acceptable, x = Criteria not met or unacceptable, ? = Criteria partially met							



4.2 Annual Strategic Irrigation Decisions

Annual strategic irrigation decisions relate to two questions. Firstly, a basic one: do I irrigate or do I sell my water? Secondly, what area and crop should I plant this year?

4.2.1 Temporary water trading

In 1994 the Council of Australian Governments (COAG) resolved to encourage the separation of water entitlements from land titles, thereby encouraging water trading. The main reason was to encourage water use in locations and practices that returned greater economic value and to allow its transfer away from areas where use was causing unacceptable environmental problems. While temporary water trading has existed since 1982 in SA, 1983 in NSW and 1987 in Vic, there has been a big increase in temporary water trading since these COAG reforms (Figure 2).

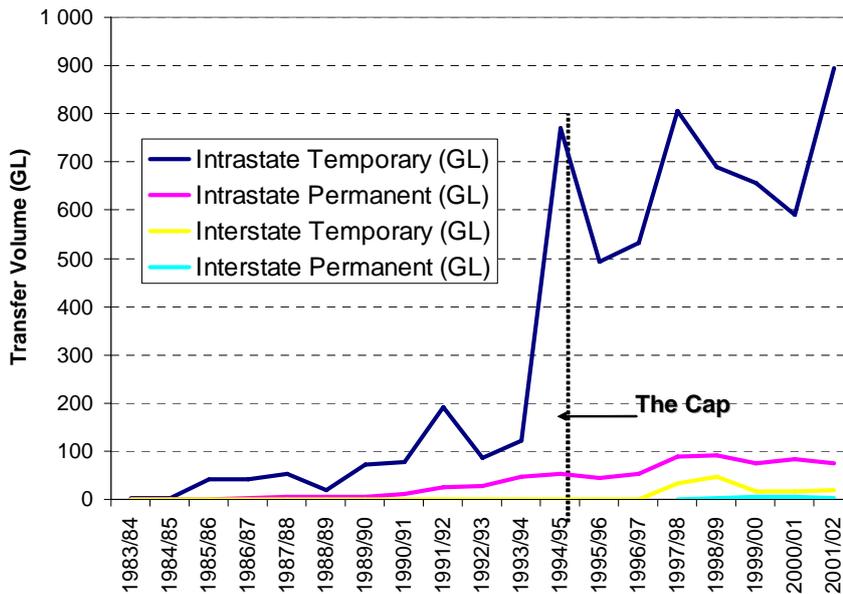


Figure 2. Temporary and permanent water trading in the Murray Darling Basin.

The creation of an active water market has created a new irrigation decision. Do I use my water or do I sell it? As can be seen in the regulated systems of the Murray – Murrumbidgee Basins there has been an eight-fold increase in temporary water trading. In some areas up to 90% of irrigation businesses have been involved in temporary water trading (Table 4). A significant number of water brokers are now involved in this business and prices vary in response to seasonal

conditions. Three internet-based trading systems now operate under the names “Water Exchange”², “Water Find”³ and “Water Move”⁴.



Water trading - buyers and sellers

The overall success of the pasture management due to the changes in the irrigation means Rob is considering trading water for the first time. This is not because he has spare water to sell but because the much improved water use efficiency means for the first time the farm is likely to use its full allocation of water and maybe need a little more. Should water be short in any year, Rob has a pre-determined strategy of dropping off low return paddocks and fully irrigating the best performing paddocks.

Case study 1.1.10

The decision to temporarily trade water and *not* irrigate will again be based on the three main drivers of environmental, social/personal and technical/financial outlined in section 2.1.

Table 4. Proportion of irrigation farm businesses that have participated in the water market by area in selected parts of the River Murray. Based on inspection of water access entitlement registers and water trading registers up to 30 June 2001 (Bjornlund, 2002).

Irrigation area	Proportion of farm businesses
Pyramid Hill/Boort (Victoria)	89%
Torrumbarry/Boort (Victoria)	65%
Murray Irrigation Limited (NSW)	88%
Private Diverters Murray Region (NSW)	73%
Private Diverters River Murray SA (Riverland)	39%
Private Diverters River Murray SA (Lower Murray)	55%
Central Irrigation Trust (SA)	15%

² <http://www.waterexchange.com.au/>

³ <http://www.waterfind.com.au/>

⁴ <http://www.watermove.com.au/>



4.2.2 *What crop, what area?*

4.2.2.1 Crop production functions

In annual cropping systems there is generally a range of crops that can be grown and strategic irrigation decisions need to be made each season. The following section sets out a framework and the information required for using crop production functions to examine which crops and what areas. The section has simplified the consideration to two main factors, water availability (allocations) and land.

The emphasis is placed on irrigation decisions to optimising, rather than maximising, the use of water from a financial perspective. However, while a quantitative financial framework can be outlined this does not imply that this is the most important driver of this irrigation decision.

Farm specific relationships between yield and water can be developed over time from farm records. Alternatively, combinations of experimental results, values from the literature and farm records can be used to generate the relationships as in Figure 3. Such crop production functions display a diminishing return function for most crops (e.g. Figure 3). The general shape of the crop production function permits the formulation of a number of rules:

1. The maximum yield physically achievable is not profitable unless water and operating costs are relatively low in comparison to commodity prices.
2. When irrigation water is plentiful and available irrigation land is limiting, then profits will be maximised by growing crops which maximise net returns per ha.
3. When water is limiting and land is plentiful, the most profitable strategy is to spread the available irrigation water equally over a larger area and maximise the average net return per ML. The limit to this spreading out process is the ability to pay for the fixed costs per ha, so some land may be left unirrigated.

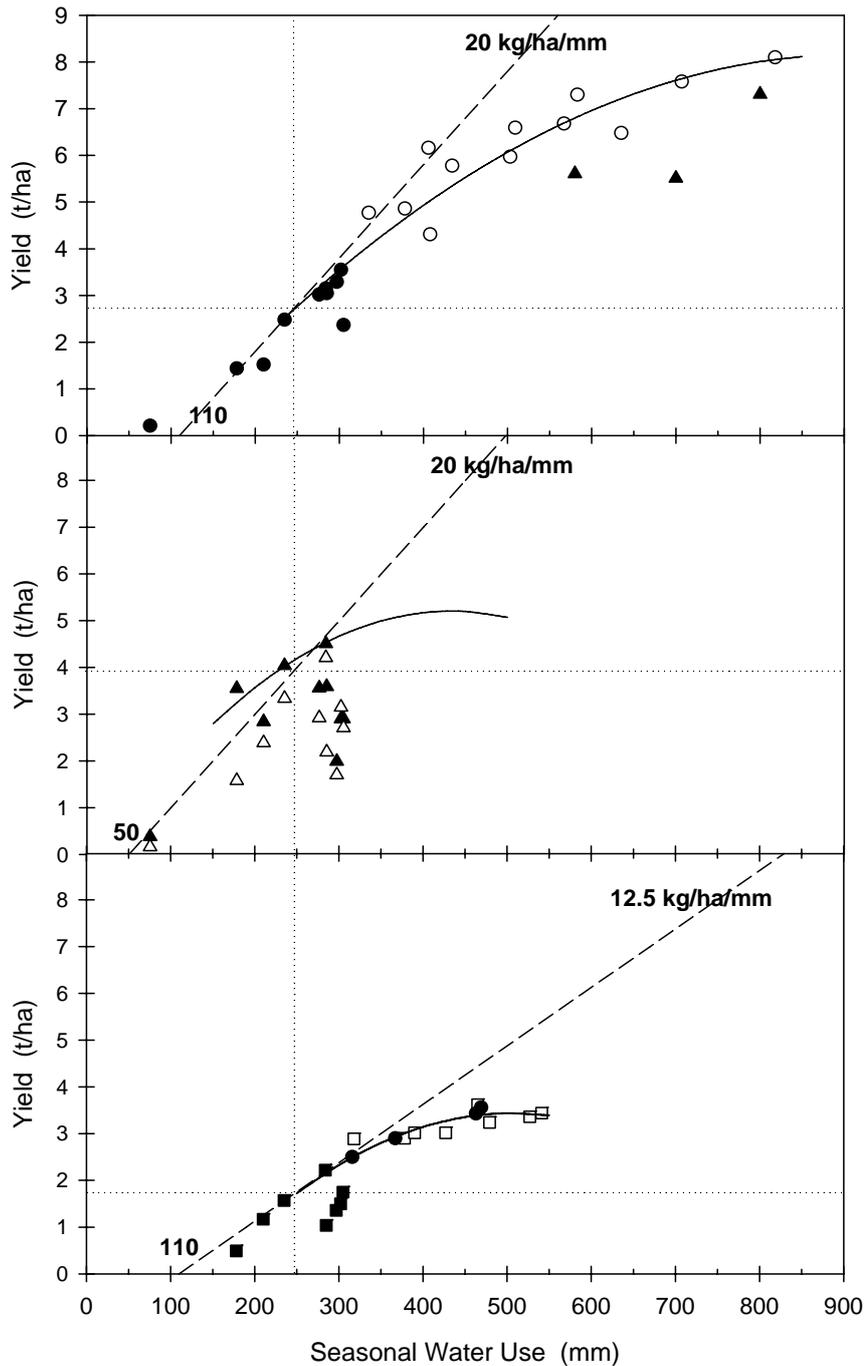


Figure 3. Production functions for wheat (top), barley (middle) and canola (bottom). Solid symbols in the top and bottom graphs are actual yield and rainfall data from farm records (Ian Lea pers. comm.) and the hollow symbols are from irrigation experiments (S. North, unpublished; Cooper, 1980). In the middle graph, solid symbols are from feed barley and hollow symbols from malting barley (Ian Lea pers. comm.) and the production function is from Gyles (2001). Dash lines represent potential yield water use efficiency (kg grain/ha/mm, (where water use (mm) is combined irrigation, stored soil water and rainfall) for cereals (French and Schultz, 1984) and canola (Hocking et al., 1997)



4.2.2.2 Irrigation returns

In the Mediterranean type climate of the southern Murray Darling Basin, winter cropping offers greater opportunity to improve water productivity in a drought or low allocation year than summer cropping.

Summer croppers can shift from rice to alternative summer crops (maize, millet, soybeans or sorghum) which use less water and allow a larger area to be cropped for a given allocation. However, these alternative crops generally require lighter soils and better draining layouts. If this is not available the question becomes primarily one of whether to grow rice or a winter crop.

In making this irrigation decision a number of factors are generally considered, such as the need to water pastures to feed stock; the time required and labour available for watering different crops at different times of the year; and the ability of the supply system to deliver water to the entire crop area in a timely fashion so drought stress is avoided. Subject to these considerations, profits will be maximised when water is in short supply if the available allocation is used on the crop that maximises net returns per ML. But which crop is that?

Winter crops can generally be grown on rainfall in a Mediterranean climate without irrigation, although at lower yields. Available irrigation allocation can be used to supplement winter rainfall and improve crop yields. Increased water productivity can be achieved by selecting the crops which maximise returns from the available irrigation water as demonstrated below in Table 5 and 6.

Yield-water use production functions for wheat, barley and canola in the Murray valley are shown in Figure 3. Assuming farm gate prices for wheat, barley and canola of \$180/t, \$170/t and \$350/t respectively, the corresponding return functions for each of these crops are shown below (Figure 4).

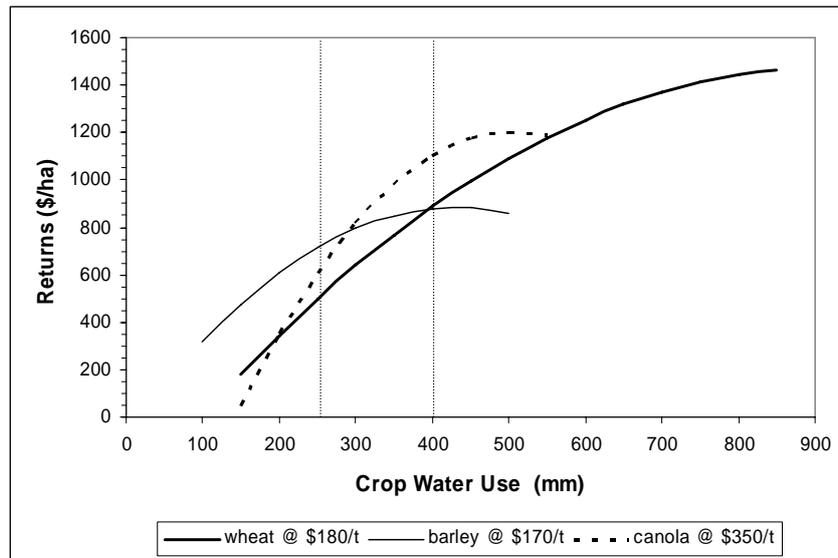


Figure 4. Return functions for wheat, barley and canola derived from the graphs in Figure 3. Median May-Oct rainfall at Deniliquin, NSW, is 250 mm and it is assumed pre-irrigation applies 150 mm. Thus, the expected maximum returns (\$/ha) from dryland (250 mm) and pre-irrigated (400 mm) crops are indicated by the dotted vertical lines.

There are two points on each line (refer to Table 5) where net returns are maximised. One of these points is for the situation when land is limiting and the other point for the situation when water is limiting. The position of these two points can be calculated from the return function when the fixed and variable costs of production are known (English & Raja, 1996).

In the example below, fixed costs are assumed equal to the opportunity cost of the land, which has been set as the net return from the dryland crop. This has been calculated as the return from each crop when water use is 250 mm (\$497, \$713 and \$603/ha for wheat, barley and canola respectively in Figure 4) minus the dryland costs of production (assumed to be \$230, \$200 and \$300/ha for wheat, barley and canola respectively). The variable cost of the water is assumed to be \$50/ML and this accounts for the additional labour, seed and fertiliser required for an irrigated crop.



Table 5. Gross margins per hectare and per ML for three crops when water is limiting. In this situation, profits are maximised when the marginal net return per ML is equal across all land units irrigated i.e. water is spread out.

	Crop		
	wheat	barley	canola
optimum water use (mm)	539	339	397
irrigation water applied (ML/ha)	2.9	0.9	1.5
cost of water @ \$50/ML	\$144	\$45	\$74
returns per ha	\$1,160	\$840	\$1095
costs per ha	\$374	\$245	\$374
Gross margin per ha	\$785	\$595	\$721
Gross margin per ML	\$272	\$668	\$490

Table 6. Gross margins per hectare and per ML for three crops when land is limiting. In this situation, profits are maximised when the marginal net return per ML is equal to the marginal cost of water.

	Crop		
	wheat	barley	canola
optimum water use (mm)	800	384	479
irrigation water applied (ML/ha)	5.5	1.3	2.3
cost of water @ \$50/ML	\$275	\$67	\$114
returns per ha	\$1,441	\$873	\$1197
costs per ha	\$505	\$267	\$414
Gross margin per ha	\$937	\$605	\$782
Gross margin per ML	\$170	\$451	\$342

Examination of the values in the Tables 5 and 6 above provides some insight into how profits might be maximised. This is best illustrated using an example farm with an arable area of 800 ha and a water entitlement of 1,000 ML. Up to half the farm (400 ha) can be in crop at any one time. With an allocation of 100% it would be possible to grow 80 ha of rice using 12.5 ML/ha to achieve a farm gross margin of approximately \$104,000 (i.e. \$1,300/ha from 80 ha). For wheat, the optimum irrigation application rate lies between 2.9 ML/ha (if water is limiting) and 5.5 ML/ha (if land is limiting). With 1,000 ML, wheat production is water limited so the profit maximising strategy is to apply the 1,000 ML over 345 ha (i.e. 2.9 ML/ha in Table 5) to achieve a farm gross margin of \$272,000.

For barley, the optimal irrigation rate lies between 0.9 and 1.3 ML/ha and for canola between 1.5 and 2.3 ML/ha. For both barley and canola, land is limiting rather than water so the profit maximising irrigation rates are 1.3 ML/ha on the barley and 2.3 ML/ha on the canola (from



Table 6). When these irrigation rates are used, the gross margins are \$605/ha for the barley and \$782/ha for the canola (from Table 6). These crops are land limited, so 400 ha of barley will produce a farm gross margin of \$242,000 with 480 ML unused. 400 ha of canola will produce a farm gross margin of \$312,800 with 80 ML unused.

It is clear that prioritising water to barley and/or canola will maximise farm gross margins in this example. Any water left unused could be allocated to grow rice during the summer or sold on the market as a temporary trade. The final decision will of course also depend upon water availability, input costs and commodity prices, seasonal conditions and crop requirements (e.g. rain at the right time for sowing), and the need to maintain a crop rotation for weed and disease control and to spread the work load and manage production and price risks. Whatever the final decision, knowledge of the yield-water use production functions for the crops being considered will provide greater insight into the optimal farm irrigation strategy for each crop as well as providing an objective basis for assessing the merits of alternative cropping strategies.



5 Irrigation Decisions and Enterprise Management

5.1 Assessing my irrigation system performance

In making irrigation decisions an assessment of the delivery capacity and crop demand is required. This is particularly important when water is limiting, not land as discussed in section 4.2.2.2. In this section the information and framework required to determine how well the system is designed to meet crop irrigation demands is outlined. The Section is written with the assumption that the irrigation system is required to match the crop's peak requirement to maximise yield. However, this is not necessarily the best financial or life style option. As such these goals should be included into the interpretation of any output.

Matching irrigation system performance to crop demand

Angelo was irrigating 28 hectares of peanuts every 5-7 days using a solid set impact sprinklers system. However, Angelo, together with his consultant, identified that the peanut crop required more water than was able to be delivered by the irrigation system. In summer the peanut crop evapotranspiration rates approached 65 mm/week. As the peanut crop has a crop factor of 1, at the peak of its development, it is necessary to apply 65 mm of irrigation each week. However, it was not simply a matter of increasing the amount of irrigation applied as additional water applied was lost via deep drainage and surface runoff thereby reducing the irrigation field application efficiency of the system. Instead the irrigation intervals had to be closer together in order to reduce the application depth whilst still providing the required 65 mm/week at peak times. To achieve this Angelo had to reduce the irrigation area by eight hectares allowing the irrigation interval and application rates to be reduced whilst operating within the constraints of the system. By doing so increases in yield were achieved and grade standards were raised.

Case study 1.1.4

5.1.1 What is the current capacity of the irrigation system?

The system capacity is the maximum flow rate (ML/ha/day; 1 ML/ha/day is equivalent to 100mm/day) that the irrigation system can deliver to the irrigated area. Irrigation System Capacity is calculated using the following formula;

$$\text{System Capacity} = \frac{\text{Volume Applied (ML/day)} \times \text{System Utilisation (\%)} \times \text{IFAE (\%)}}{\text{Area Irrigated (Ha)} \times 100}$$

Where,

Volume Applied (ML/day) is obtained from the water applied over an irrigation cycle divided by the days required to complete the cycle, *System Utilisation* is the amount of time during an irrigation cycle that the irrigation system can operate. This is influenced by downtime due



to irrigation changes, farming practices (cultivation, spraying and fertilising) and allowances for breakdowns and allowances for system maintenance. For example, a system that operates for 20 hrs per day will be utilised for 20/24 hours giving a system utilisation of 83%.

Irrigation Field Application Efficiency (IFAE) is the amount of applied water that is retained in the soil. The major sources of water loss which reduce IFAE are evaporation, deep drainage and surface runoff. Typical IFAE for various systems are shown in Table 7. For an IFAE value specific to an irrigation system and location refer to section 5.1.3.1.

Area Irrigated is the total area irrigated during the irrigation cycle used to estimate the Volume Applied.

Generally the area irrigated is the variable which is most important in irrigation decisions. This can be varied depending on the crop, season, irrigation strategy and risk tolerance. Section 4.2.2 provides a framework for these considerations.

IFAE can be modified through management, refer to Section 5.1.3.1 for details.

5.1.2 What is the peak irrigation requirement?

Different crops will have different irrigation requirements. An extreme example is the irrigation requirements of a winter crop compared with a summer crop. To ensure the irrigation system is capable of meeting the new crop's demand, an estimation of the peak irrigation demand is required. This can then be compared with the irrigation system's current capacity (5.1.1) to determine if the irrigation system is capable of supporting the proposed crop.

To determine the peak irrigation requirement, a knowledge of the soil water holding capacity, sensitivity of the potential crop to stress at different times and an understanding of how the grower is likely to operate the system is required. Based on this information an appropriate peak evapotranspiration (E_{t_0} , mm/day) can be used to determine the peak irrigation requirement. The procedure for calculating the E_t of the crop (E_{t_c}) is given in Section 5.2.3.2.

Soil properties will have a major impact on the selection of an appropriate E_{t_0} value. The soil water holding capacity acts as a buffer, determining the interval between irrigation events. Deep, well structured soils are able to store significant volumes of water. This store of water can be drawn upon by the crop during periods of extreme demand, e.g. hot, windy conditions. This reduces the reliance on the irrigation system to supply water during these extreme periods. By contrast shallow, poorly structured soils store little water. Crops grown on these soils can quickly exhaust these supplies during periods of extreme demand placing greater reliance on the irrigation system. The infiltration rate of the soil may, in some circumstances, also have an



impact on the peak irrigation requirement. Low infiltration rates will reduce the buffering capacity by limiting the amount of water than can be infiltrated and stored in the root zone.

The sensitivity of crop yield to water stress will also influence the choice of an appropriate E_{t_0} value. If the crop is sensitive to water stress during the hottest months of the year, then there is more demand placed on the irrigation system to meet the peak requirements. For example, cotton flowering, which is very sensitive to water stress, coincides with the hottest time of the year. If the irrigation system is unable to meet the crop's water demand then this will have a major impact on yield. By contrast, failure to meet the peak demands of a lucerne or pasture crop may cause a short term reduction in growth, but would not have the same large impact on overall yield as for cotton.

Finally, consideration of the operator's lifestyle and attitude to risk is required. These should be explicitly discussed to ensure any proposed changes are consistent with the operator's objectives and way of managing. Failure to do so can result in the best irrigation system performing poorly.

The selection of an E_{t_0} value will depend on a range of factors outlined above and will vary for each situation. These factors will determine the appropriateness of using E_{t_0} values from the average or hottest year, average value of the hottest month or maximum daily E_{t_0} for the hottest month. For example, the E_{t_0} value selected for an irrigation enterprise growing high value crops on a shallow sandy soil with drip irrigation will require an irrigation system to cope with extreme conditions. Under these conditions a maximum daily E_{t_0} for the hottest month may be appropriate. By contrast, surface irrigating lucerne, on a deep clay soil, may use an average daily E_{t_0} for the hottest month of an average year.

Matching system to crop demand – no room for error

Paul was concerned about the lateral move irrigation system that irrigates 32 ha of potatoes growing on red volcano clay/loam soil. The system was designed to apply 50 mm per week to the 32 ha. Late potato crops growing into summer have higher water demands as evapotranspiration rates are up around 55 mm per week. The crop factor for potatoes at the peak of the crop cycle is 1 to 1.2 giving an estimated water demand of 55 – 66 mm per week. Thus during these peak periods the irrigation system struggles to keep up with demand and the water stored in the soil profile becomes increasingly important in preventing water stress from reducing yields. As a result care is required to ensure soil water content is not drawn down prior to the peak demand period. Because the system capacity is exceeded during peak demand Paul would have to be comfortable with some risk of reduced yields in dry, hot years.

Case Study 1.1.6



5.1.3 How well does the irrigation system perform in the field?

An irrigation system may not be performing as well as expected leading to reduced yields. Thus a performance evaluation of the irrigation system may be required to support other irrigation decisions and improve productivity. The performance evaluation of in-field application systems can be divided into the two major components of water losses and uniformity of application. Although both components are influenced by system design and management practices, the losses are predominantly a function of management while the uniformity is predominantly a function of the system design characteristics (Solomon, 1993).

In this section we concentrate on the approaches to assess application efficiency of a single irrigation event, in one field (Irrigation Field Application Efficiency, Barrett Purcell & Associates 1999). For whole season and farm considerations of application efficiency refer to Fairweather *et al.*, (2005).

5.1.3.1 Irrigation Field Application Efficiency (IFAE)

The major sources of water loss by in-field irrigation systems are due to evaporation (from the atmosphere, the free water surface or the soil surface), deep drainage or by surface run-off. The dominant loss mechanism is closely related to the method of application but in all cases may be substantially reduced by the adoption of appropriate management practices. IFAE describes the in-field losses and hence the performance of the irrigation system.

$$\text{IFAE} = \frac{\text{Irrigated water available to the crop}}{\text{water received at the field inlet}}$$

Where:

Irrigated water available to the crop is typically estimated from soil water measurements before and after irrigation once drainage has ceased (See Section 5.2.2 for methods),

Water received at the field inlet is estimated from flow meters.

Typical IFAE values for the most common irrigation systems indicate that higher efficiencies can normally be expected through the use of micro-irrigation or low pressure overhead sprinkler systems (Table 7).

However, substantial water losses, reducing the application efficiency, can occur due to inappropriate management practices. For example, hand-shift sprinkler systems are often operated so that excessive watering occurs, to try and reduce the labour involved in shifting hand lines. However, this usually results in substantive losses due to either deep drainage or surface run-off, substantially reducing application efficiencies. Another example is the use of spray irrigation systems during periods of high evaporation potential resulting in increased evaporation losses directly to the atmosphere.



Human nature overriding engineering specification
 While working on dairies in the Hunter Valley of NSW, Rob started his irrigation experience with hand-shift systems. The irrigation decision was simply to apply two inches of water each shift to limit the labour time taken in moving the pipes. The irrigation was done when time allowed, so it was common to apply too much.

Case study 1.1.10

Table 7. Typical irrigation field application efficiencies (IFAE) for irrigation application systems.

Type of system	IFAE (%)
<i>Surface irrigation</i>	
Basin	60-85
Border	60-85
Furrow	60-85
<i>Sprinkler irrigation</i>	
Hand move or portable	65-75
Travelling gun	60-70
Centre pivot & lateral move	75-90
Solid set or Permanent	75-95
<i>Micro-irrigation</i>	
With point source emitters	75-90
With line source emitters	70-85

5.1.3.2 Application Uniformity

Measures of uniformity commonly used to assess irrigation system performance include the Christiansen Uniformity Coefficient (CU), (Christiansen 1942) and Distribution Uniformity (DU). Whilst CU and DU are used across irrigation systems, CU is more commonly used for sprinkler irrigation systems while DU is more commonly used for surface irrigation systems. In the tables below, the application uniformity of a travelling gun irrigator is calculated to demonstrate both CU and DU (Figure 5).



Figure 5. Catch cans laid out under a travelling gun irrigator to record the depth of water applied for use in calculating application uniformity (Table 8).





Table 8. provides the data recorded from sixteen catch cans spaced at 5 m intervals under a travelling irrigator. Using this data both CU and DU are calculated.

Catch Can	Distance (m)	Applied Depth (x_i , mm)	Absolute deviations $ x_i - \bar{x} $
1	0	41	1
2	5	67	25
3	10	39	3
4	15	31	11
5	20	36	6
6	25	48	6
7	30	51	9
8	35	53	11
9	40	46	4
10	45	34	8
11	50	27	14
12	55	32	9
13	60	36	6
14	65	34	8
15	70	39	3
16	75	55	13
Mean (\bar{x})		42	9

Christiansen's Uniformity Coefficient is given by:

$$CU = 100 \left(1 - \frac{m}{\bar{x}} \right)$$

where m is the mean absolute deviation of the applied depths x_i and is given by:

$$m = \frac{\sum |x_i - \bar{x}|}{n}$$

\bar{x} is the mean applied depth, and n is the number of depth measurements.

$$m = \frac{1 + 25 + 3 + 11 + 6 + 6 + 9 + 11 + 4 + 8 + 14 + 9 + 6 + 8 + 3 + 13}{16}$$

$$m = \frac{144}{16}$$

$$m = 9$$

therefore

$$CU = 100 \times \left(1 - \frac{9}{42} \right)$$

$$CU = 79\%$$



Distribution Uniformity is given by:

$$DU = \frac{\text{Mean of the lowest 25\% of applied depths}}{\bar{x}} \times 100$$

Table 9. Catch can applied depths sorted in ascending order (from Table 8).

Applied depth (mm)															
67	55	53	51	48	46	41	39	39	36	36	34	34	32	31	27

$$DU = \frac{(34 + 32 + 31 + 27) \div 4}{42} \times 100$$

$$DU = \frac{31}{42} \times 100$$

$$DU = 74\%$$

The DU and CU values of 74 and 79%, respectively, indicates that the travelling gun irrigator has a less than satisfactory application uniformity. Factors such as wind during the assessment, nozzle type and lane spacing could have resulted in the lower application uniformity.

In most cases, the potential distribution uniformity in a well designed and maintained application system is greater than 85% (Table 10). The following sections discuss performance assessment of in-field irrigation systems and techniques to improve application efficiencies and distribution uniformities.

Table 10. Irrigation systems and potential distribution uniformities (Burt, 1995)

Irrigation System	Potential Field DU (%)
Permanent under tree sprinkler	94
Linear move	92
Orchard drip	90
Sloping furrows	89
Level furrows	87
Border strip	85
Row crop drip	90
Hand move sprinkler (w alt. sets)	85
Hand move sprinkler (w/o alt. sets)	75



Improved application uniformity, increased yields, reduced water applied
After making changes to the lateral move irrigation system Paul noticed a more consistent size across the field in his potatoes compared to that of previous years. The potato crops grown in 2002 produced on average 39.5 t/ha. In 2003, after changing the sprinklers from Nelson D3000 spray heads to Nelson S3000 spinner sprinklers, potatoes grown at similar times and in similar climatic conditions produced an average yield of 47 t/ha. Good farm management by Paul and guidance from irrigation advisor Fabian Gallo resulted in an increase of 20% in potato yields. Water usage in the potatoes was also decreased by 1 ML/ha to 5.5 ML/ha.

Case Study 1.1.6

5.1.3.3 Performance evaluation of surface systems

The performance evaluation of surface irrigation involves an assessment of both the volume and uniformity of water stored within the soil. The soil infiltration characteristic is one of the dominant factors affecting surface irrigation performance and exerts its influence by controlling the rate of advance of irrigation water down the furrow or bay. Knowledge of the spatial average value of this characteristic is required for the optimisation of surface irrigation. It should be borne in mind that soil properties which determine infiltration rates can change both over the short and long term. This means that measurements need to be repeated over time or real-time measurement systems developed (e.g. Khatri and Smith, 2006).

A common and effective method of determining infiltration under surface irrigation is based on measurements of furrow/basin inflow rates, irrigation advance rates, hydraulic cross sections and tail water volumes using the two point method of Elliot and Walker (1982). More recently the INFILT program of McClymont and Smith (1996) and the IPARM model of Gillies and Smith (2005) have been used to determine the field infiltration characteristics from this measured data. This most recent work suggests that a single point measurement can give good estimates of infiltration.

Once the infiltration characteristics of the field have been determined, irrigation events and performance is typically simulated using a surface irrigation model such as SIRMOD. SIRMOD simulates the depth and variation of water applied to the field and evaluates the performance of the irrigation event also by calculating application efficiency and distribution uniformity. The irrigation performance determined by SIRMOD is contained to one furrow which is used to represent the entire field. SIRMOD also enables the operator to optimise operational parameters such as furrow flow rate and cutoff times to maximise application efficiency and distribution uniformity.

Accurate measurement of the inflow rate is critical to the estimation of



the infiltration characteristic. Two factors have a major influence on the robustness of infiltration estimation. Inaccuracy in the flow measurement will cause uncertainty in the estimated infiltration rates. Uncertainty in the infiltration estimation increases rapidly as the percent of inflow that is infiltrated decreases (Trout and Mackey, 1988). Both of these influence the performance measurements of the irrigation system.

5.1.3.4 Performance evaluation of overhead systems

An outline of the common measuring devices and procedures for the evaluation of sprinkler irrigation is provided by Merriam *et al.*, (1980). The evaluation of sprinkler irrigation systems typically involves an assessment of the volumetric discharge rate and the uniformity of the discharge. Guidelines for the evaluation of sprinkler systems are provided in the ISO standards (a) ISO 15886-3:2004 - Procedure for sprinkler distribution testing for research purposes (ISO, 2004), (b) ISO 8224-2:1991 - Procedure for Travelling Irrigator testing and performance recording (ISO, 1991) and (c) ISO 11545:2001(E) - Test procedures for determining the uniformity of water distribution of centre pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles (ISO, 2001).

System performance – achieving distribution uniformity – measure don't assume

The sprinkler uniformity was measured and a DU (Distribution Uniformity) of 87% revealed. Ideally centre pivots and linear moves should have a DU of 92% and over. After providing these details Paul changed all sprinklers from the Nelson D3000 spray heads to Nelson S3000 series spinners. The DU tests were redone and the Nelson S3000 series sprinklers gave a DU of 97%.

Case Study 1.1.6

Field uniformity testing of multi-sprinkler systems (i.e. solid set and hand shift) normally involves using a grid pattern of catch cans which extends beyond the nominal sprinkler distance to capture overlap effects and enable the evaluation of sprinkler pattern distortion by wind. Wind speed and direction should also be measured. The performance of micro-sprinkler systems has been commonly assessed using catch can methods with the cans spaced at 0.3 m intervals in one quarter of the wetted circle (Pandey *et al.*, 1995; Post *et al.*, 1985; Boman, 1988).

The ASAE standard (1997) for performance evaluation of lateral move and centre pivot machines recommends that collectors (i.e. catch cans) are spaced at the lesser of: (i) 30% of the average wetted diameter of the sprinklers, or (ii) 4.5 m. For lateral moves, two rows of collectors are recommended spaced no more than 2 m apart.

It should be noted that for sprinkler systems discharging the water



above the plant canopy, the system uniformity may be different to the root zone soil water uniformity due to the plant canopy intercepting and altering the flow of water to the soil.

Sprinkler discharge rates can be measured by redirecting the water (using a length of flexible hose) from the nozzle into a container of known volume, and measuring the time required to fill the container. Assessments of discharge from micro-sprinklers may be obtained by inverting the sprinkler nozzle over a volume graduated cylinder for a set period of time (Yurgalevitch *et al.*, 1995). In each case, it is important that sufficient measurements are made to accurately calculate the average and standard deviation of the discharge. Nozzle pressures may be measured using a pitot tube (<1 mm diameter) connected to a pressure gauge. The tip of the tube should be placed in the nozzle jet at approximately three millimetres from the exit point so that the flow rate is not reduced (Merriam *et al.*, 1980; Zimmermann, 1991). While some workers have measured sprinkler pressure by replacing the nozzle with a pressure gauge (e.g. (Yurgalevitch *et al.*, 1995), this is not normally recommended as the reduced system flow rate associated with the blocked nozzle influences the overall system pressure (Merriam *et al.*, 1980).

5.1.3.5 Performance evaluation of micro irrigation systems

The performance of micro-irrigation systems is heavily influenced by the uniformity of application. However, unlike other systems, the uniformity of drip irrigation systems is not only a function of the design characteristics but is also significantly affected by maintenance and management practices. Therefore, measuring application uniformity in micro-irrigation systems is an important component of performance evaluation and the assessment of the likely system longevity (Sadler *et al.*, 1995). The ASAE Standard EP458 - Field evaluation of micro-irrigation systems (ASAE, 1997) provides an outline of the most commonly adopted performance evaluation procedure.

Discharge uniformity is assessed by measuring discharge from a number of emitters using a catch can methodology similar to that used for sprinkler systems. For subsurface systems, this involves excavating the soil around the emitter and collecting the water quantity discharged (Sadler *et al.*, 1995). Trials to confirm that the excavation of subsurface emitter does not affect the emitter flow rate have found that flow rates increased by only 2.8-4.0% above the discharge measured when the emitters were embedded in the soil (Sadler *et al.*, 1995).

Pressure in the micro-irrigation laterals is also commonly measured to identify non-uniformities due to friction losses and head differences along laterals. Pressure may be measured at the flush point or end of the lateral using a standard pressure gauge or at specific points along the lateral using a needle point pressure gauge inserted directly through the tape or tube. As a rule of thumb variation in pressures throughout



the system should be less than 15%. The models used for the design and evaluation of drip irrigation systems may also be used to evaluate the application uniformity of subsurface systems based on the measured pressures and the system design characteristics (Phene *et al.*, 1992; Feng and Wu, 1990; Wu and Yue, 1991; Wu, 1992).

The main causes of low emission uniformities in micro-irrigation systems arise from poor design and manufacture, poor pressure regulation, clogged emitters, leaking laterals and non-uniform pressures. Minor causes are due to use of different sized emitters, inadequate pump pressures, sprinklers being blocked by low hanging branches, and missing emitters (Yurgalevitch *et al.*, 1995; Hanson *et al.*, 1995).

5.2 Irrigation scheduling - when and how much to irrigate?

Irrigation scheduling is a decision making process that occurs throughout the growing season to determine when and how much water should be applied. The aim of irrigation scheduling is to manage the soil water status, and hence crop, at an optimum level for yield (and/or quality) to achieve the desirable profitability, lifestyle or environmental outcome (see Section 2.1). Traditionally, when water was readily available irrigation scheduling focused on applying water to match the crop's requirements to achieve full production potential.

More recently, declines in water availability and increases in the cost of water have focused attention on optimising irrigation to maximise farm profits. The optimal use of available water across the farm has been covered in Section 4.2.2.2. In this section the day-to-day delivery of water to the crop to achieve the whole farm strategy is outlined.

5.2.1 Irrigation strategies

There are two distinct irrigation strategies. These strategies have a major impact on the information and monitoring required and its interpretation.



5.2.1.1 Cyclical irrigation strategy

The cyclical irrigation strategy uses the soil water holding capacity to supply the crop with water on a daily basis. The crop extracts water from the soil until a nominal refill point is reached. Irrigation is applied to the soil to bring the soil back to field capacity (full point), or some other soil water content. This strategy is common in broadacre irrigation of crops and pasture. Irrigation scheduling in this context is strongly focused on characterising the refill and full points (see section 5.2.2.3 for definitions and setting of refill and full points). This information is then used for both triggering the irrigation event (refill point) and determining the amount of irrigation required.

5.2.1.2 Constant irrigation strategy

The constant irrigation strategy uses frequent irrigation events to maintain the soil water content in a reasonably narrow soil water range. As a result the crop roots experience a reasonably constant soil water environment over time but typically not all the soil is the same, i.e. only localised areas of the soil are kept moist. This strategy is common in horticultural crops using drip or micro-irrigation systems and broadacre crops and pastures under centre pivot and lateral move irrigation systems. The most extreme form of this strategy is the open-hydroponics system which attempts to match water application with crop demand continuously (Falivene 2005). Irrigation scheduling in this context is focused on determining how much water has been lost through Et, on daily and even hourly time steps, and if too much or too little water is being applied. This information is then used to determine both the duration and frequency of irrigation.

The irrigation decision in context

The timing of irrigation is not an exact science. It involves consideration of factors ranging from other agronomic operations (spraying and fertilising), predicted weather through to social considerations.

Today Allan's decision making process is determined by the following in order of priority:

1. Chemical spray program of the nursery cotton lines. This occurs every 7-10 days and watering has to fit around it.
2. Weather conditions now and the forecast
3. Visual appearance of the crop
4. Presence of casual staff who come to pull rogue plants from the nursery lines
5. Neutron probe (Allan had previously engaged a consultant. During this period this information was prioritised 2nd after the spray program. Allan has now incorporated the learnings from soil water measurements into his experience.)
6. Public holidays
7. Annual holidays, family events, etc.

Case Study 1.1.2



5.2.2 When do I irrigate?

Farmers use many methods to determine when they should next irrigate. The common feature is that they all rely on some assessment of the need of the crop for water. Furthermore, the importance of the decision varies throughout the season depending on the growth stage of the crop, its sensitivity to water stress and the effect on yield.

Information sources for determining when to irrigate include past experience, visual crop assessment, direct measurements of crop growth, soil water monitoring equipment, soil water balance using crop Et (weather based) and weather forecasts.

Sources of information

Mike uses soil water probes as his main source of information for deciding when to irrigate.

Secondly, Mike uses crop information obtained from his crop consultant, particularly nodes above white flower for cotton.

Thirdly he takes note of weather forecasts. Mike does not limit himself to one forecast source or model but consults several web sites to check consistency. If rain appears certain within a few days, he may hold off irrigating.

Case Study 1.1.1

The most appropriate methods will be dependent on the crop and its response to water, the irrigation system and the irrigation strategy being employed (see Section 5.2.1). Typically a combination of methods will be used which are cross referenced. For example, a farmer may use detailed plant measurements for a couple of years to ‘calibrate’ his observation and soil water measurements. After this they may rely on a simpler trigger.

Cyclical irrigation strategies are more reliant on soil water measurements for determining the timing and amount of water. As such the approaches outlined in this section are more applicable to cyclical irrigation strategies where irrigation is triggered by some assessment of the crop’s need for water. By contrast, the constant irrigation strategy relies less on an irrigation trigger point. Instead, irrigation is applied frequently with the amount or frequency often determined by Et estimates. Soil and plant monitoring in the constant irrigation strategy is then used as a check to ensure that the crop is not under or over irrigated.

5.2.2.1 Experience and routine



Over time farmers build up substantial irrigation experience specific to their farm through trial and error. Such experience may incorporate the learnings from using more objective monitoring tools which are no longer routinely used, such as soil water measuring tools, or a subjective indication of crop stress such as wilting, leaf curling, leaf burn, or loss of vigour. Over time irrigation practices evolve which apply water on a rotational basis based on either set time intervals or previous experience. These subjective assessments run the real risk of both under- and over-irrigating.

Calendar and crop observations

Don's method of deciding when to irrigate is based on the irrigation schedule identified in the farm's Irrigation and Drainage Management Plan prepared by a local consultant, which was a 6 day rotation around all the blocks, followed by 6 days off. With the recent hotter, drier seasons, he has altered this to be 3½ days on and 3½ days off. The change was partly prompted by an indicator of water stress in the lucerne – a 'waxy' look resulting from the leaves lifting a little. The change was intended to better meet the plant's water requirements and also to allow for reduced water supply from falling water levels in the bore. The new irrigation schedule means he stops irrigating only to bale the crop.

Case Study 1.1.3

5.2.2.2 Plant responses

The reduction in plant growth due to water stress is the most direct and sensitive indicator of the onset of water deficit stress. It has the added advantage of providing an integrated assessment of water availability when the soil water content varies spatially. Measurements such as fruit diameter growth (apples, stonefruit), stem extension (e.g. sugarcane; Figure 6), node lengths and stem diameter are reasonably easy to undertake. Measurements of plant growth can be used to 'calibrate' the output from monitoring tools, such as tensiometers, soil water probes and Et models to achieve the desired growth rate or quality parameter.

An example using plant measurements to determine irrigation scheduling in sugarcane growing in the Burdekin (Attard *et al.*, 2003) is given below. The sugar stalk has a maximum elongation rate of 27 mm/day (Figure 6). As the soil water deficit (estimated from E_t) increases a corresponding decrease in stalk elongation rate occurs. Irrigation and rainfall events reduce the soil water deficit and increases in stalk elongation rates are observed. By using this information a grower can set the threshold for irrigation based on soil water content estimates from E_t models or soil water probes. For example, if the sugarcane grower wished to maintain the stalk elongation rate at 50% or more of its maximum, then irrigation would be triggered by a soil water deficit of approximately 45 mm.

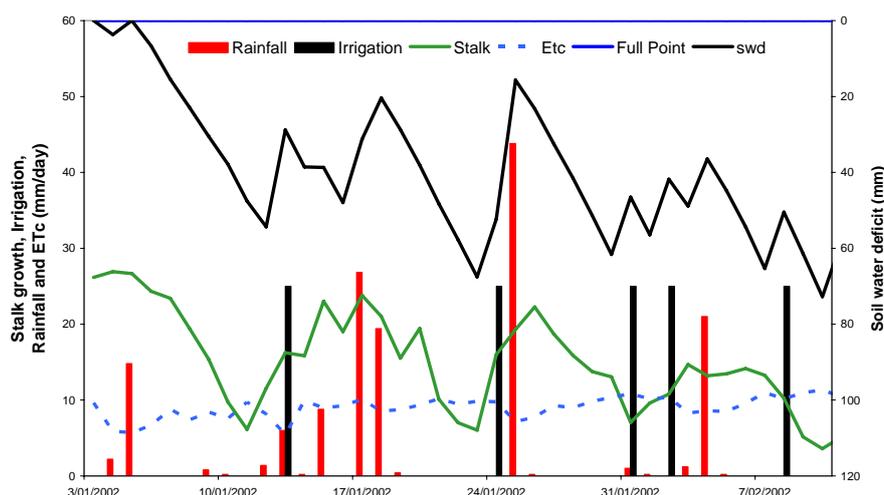


Figure 6. Sugarcane stalk growth rate and soil water deficit in the Burdekin (Attard *et al.*, 2003).

In undertaking plant measurements it is recommended that a well-watered reference plant is also measured. This can effectively remove any growth rate variations not due to changes in soil water content. Examples of such factors include variations in temperature, sunlight and phenology (growth stage). Also waterlogging immediately after irrigation can reduce plant growth despite the soil water deficit being very low. These factors need to be considered when using plant measurements for ‘calibrating’ other more routine monitoring tools.

Direct measurements of plant growth have also produced the understanding of which parts of the crop growing cycle are more sensitive to water. This allows irrigation managers to focus their attention on these periods. The ability to directly measure plant response to water is becoming more widespread as the tools become automated, smaller, cheaper and more robust.

5.2.2.3 Soil water measurements

There is a wide range of soil water sensors and techniques available that are capable of measuring either soil water content or soil water potential. These soil water monitoring tools have been summarised into comprehensive comparative tables of the attributes and operating constraints of the various sensors (Charlesworth, 2005). In grapes and cotton such soil probes are used by upwards of 30% of growers (Figure 1, Section 3.2). Methods for developing site specific calibrations for soil water probes are given in Greacen *et al.*, (1981) Chanasyk and McKenzie (1986) and Charlesworth (2005).



Changing between soil water measuring methods

Mike has used C-Probes (Agrilink) for 5-6 years, after using a neutron probe for many years. To gain confidence in the new probes Mike used both for one year to give a basis for calibrating the C-probes.

Case Study 1.1.1

Soil water measurements provide information at a particular point in the field. The location of the limited number of sensors is of considerable importance. The small numbers of sensors mean that it is not possible to account for the soil and crop variability across the whole field or farm. Even if there are enough sensors to account for this variation, irrigation systems are not able to readily deliver different volumes to different parts of the field. Thus the positioning of soil water sensors must subjectively account for these differences.

The overall management of a crop (fertiliser, cultivation, pest and disease control, variety) takes into consideration field variation. Soil water sensor placement needs to either average out this variability or measure a point in the field on which management decisions will be based. Using soil water sensors the irrigation schedule is designed to satisfy the plant requirements in that particular part of the field which is used to represent the whole field or crop.

The measurement of soil water content allows two important levels in the cyclical irrigation strategy to be set – the Full Point and the Refill Point.

The Full Point (Field capacity; drained upper limit) is the maximum amount of water the soil can hold against gravity. Field soil profiles that are saturated will drain as water moves through the larger pores in response to gravity, initially at a fairly rapid rate, then at an ever decreasing rate.

The Full Point can be determined using measurements of soil water content over time following either heavy rain or irrigation. In Figure 7 such patterns can be observed when excess water was applied. The decline in soil water content is rapid, as the water drains from the profile, and then slows once the Full point is approached. The Full Point can also be set by saturating the soil, covering with plastic sheeting (to prevent evaporation) and measuring the water content. The Full Point is when a steady content (within measurement error) occurs. Defining the Full Point works well in field soils that are free draining and do not have water tables present. Where drainage is very slow, as in heavy clay soils, it is often very difficult to identify the Full Point as the rate of water content change is very slow, even from saturation.

The Refill Point is the soil water content when irrigation should be applied. Typically, it is the soil water content before critical plant functions such as leaf growth and transpiration start to decline because of reducing soil water content. Typically it is the soil water content



before plant growth is reduced because of declining soil water. The actual soil water content can vary depending on the sensitivity of crop growth and yield to water stress at various times. In particular the refill and full point may be altered if regulated deficit irrigation or partial rootzone drying methods are being employed (for details of these methods refer to Kriedemann and Goodwin 2005). Below the refill point the crop is still able to extract water but reductions in crop growth and yield are likely.

The measurement of soil water content, and status using tensiometers, can be used to set the Refill Point and Full Point (Figure 7). Refill Points can be established by examining the slope of the relationship between soil water content and time. Initially the slope is at its steepest as water is rapidly withdrawn from the soil by the crop roots. During this phase the crop roots extract readily available water from the larger soil pores. As the soil dries water becomes harder to extract and the crop can not extract water at the maximum rate. At this stage the slope flattens out. The point where the slope changes from steep to a flatter slope can be an indication of the Refill Point. Some care is required in setting the Refill Point as changes in slope can be caused by other factors. Changes in weather conditions (e.g. cooler cloudy weather) and rapid crop canopy growth can also cause changes in soil water extraction rates. This can be accounted for by maintaining a well-watered reference within the crop.

Typically, other information is also used to confirm the Refill Points. The water uptake of roots in different soil layers can be used to help set the refill point (Figure 8). Information on setting the Refill Point can be obtained by looking at the relative rates of water extraction from the topsoil and deeper soil layers. Initially, when the crop is not limited by soil water, water uptake from the topsoil will be most rapid. As the soil dries water uptake from the topsoil will slow more quickly than in the deeper soil layers, i.e. the deep soil layers will become more important in supplying the crop when the easily available water from the topsoil is nearly exhausted. Essentially, these deeper roots are the plant's insurance sustaining the crop as the soil dries out. At this point soil water is limiting crop water use and this can help indicate the Refill Point.

The plant response to soil water is also an important method for setting the refill point (Section 5.2.2.2).

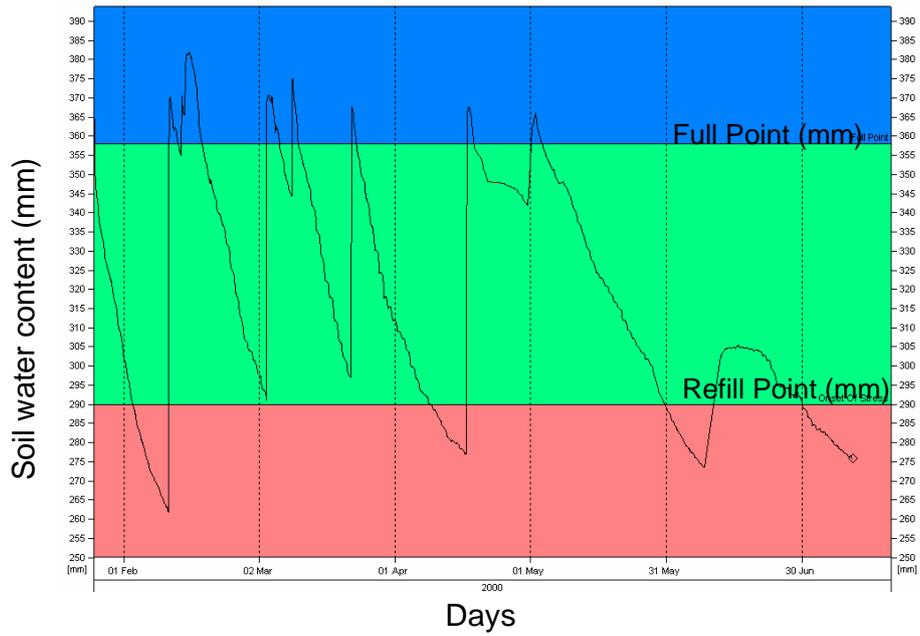


Figure 7. Changes in total soil water content (to 1m) from February to June showing the cyclical change in soil water content between the Full Point and the Refill Point (Onset of Stress). Irrigation and rainfall events are responsible for the rapid increase in soil water content while crop water extraction is largely responsible for the steady decrease in soil water content.

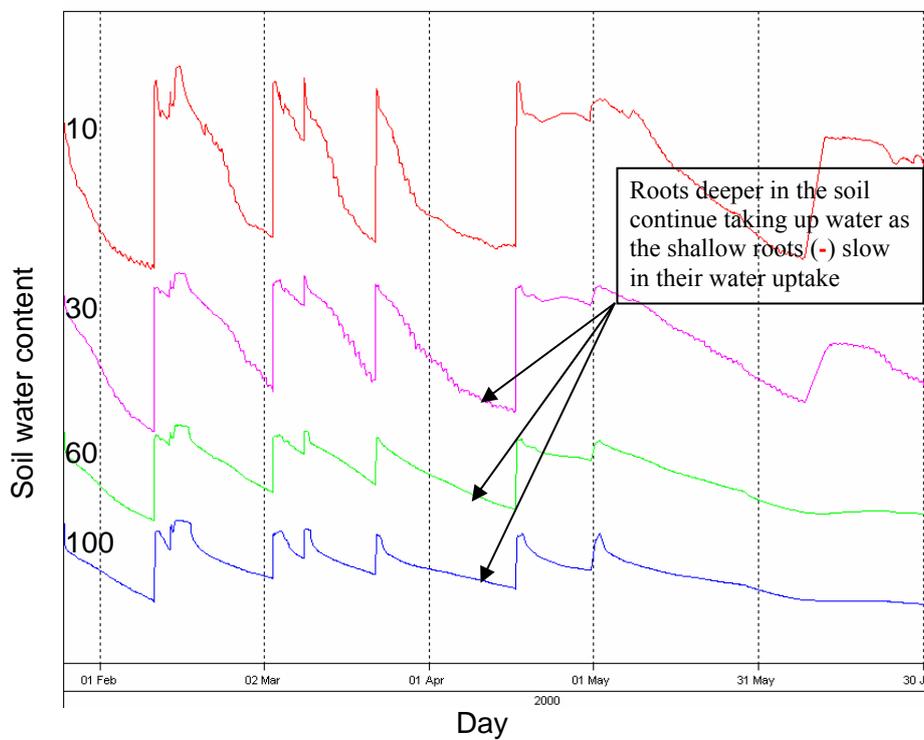


Figure 8. Changes in soil water content over time at four soil depths.



5.2.3 How much water do I apply?

To determine the amount of water to apply through irrigation the following is required:

1. How much water have I lost from my soil through Et, deep drainage or run-off?
2. How much water can my soil hold?

The maximum amount of water that should be applied is that which fills the soil profile to field capacity. Water supplied in excess of this amount will primarily be lost to surface runoff or deep drainage (see Section 6). Knowledge of the current soil water status and that of the Full Point (field capacity) is needed to determine the amount of water to be applied. This amount can be determined by direct soil water measurements (5.2.3.1) or by estimation using a simple water-balance model (5.2.3.2).

5.2.3.1 Soil water measurements

Soil water measurements are a direct method of determining how much irrigation to apply. Once the full point is established measurements or estimations of the soil water content can be used to determine the amount of irrigation required. For example, in Figure 7 a full point of 357 mm has been set. In mid April the soil water content declined to 277 mm. To return the soil to the full point 70 mm (0.7 ML/ha) was required.

Soil water measurements can also be used to provide information as a feedback mechanism to improve irrigation scheduling based on Et techniques. Howell (1996) suggests that since there is some degree of error in each of the measured or estimated components (particularly Et) of the water balance scheduling models, measurements of soil water should be periodically acquired to adjust the output from these models for irrigation application and rainfall infiltration differences.

On-farm trials – try before you commit

A trial plot comprising 1,000 trees was monitored and changes were made that reduced the time between irrigation to 2 – 3 days and the length of irrigation to 3 – 4 hours. Over a period of five months available water was maintained at a constant level in the root zone and nutrient leaching was reduced. Yield increased by 130% from the previous season and 100 % compared to the rest of the farm irrigated under Bruce's usual schedule. These values were repeated for 2 years. In 2005 Bruce scheduled his whole property under the changed irrigation practices and is achieving above average district yields putting him in the top 5% of growers in his region.

Case Study 1.1.5



5.2.3.2 Estimation of soil water balance

Irrigation can be scheduled using a simple soil water balance model. Such a model will estimate the timing of irrigation and the amount required based on predictions of water stored in the soil. Typically, a soil water balance model is the application of a daily water balance equation with the following features:

$$P + I + G + (SW_1 - SW_2) = Et_c + R + D$$

Where *water inputs are*

P = precipitation (rainfall)

I = depth of irrigation applied during the time period

G = upward movement of groundwater into the rootzone

SW₁ and SW₂ = the depths of soil water stored in the root zone at the start (t=1) and end (t=2) of the time period, respectively (i.e. the decrease in stored soil water) assuming starting with soil full.

water outputs are

Et_c = crop evapotranspiration

R = runoff

D = deep drainage below the root zone and the depth of the soil profile used to establish SW₁ and SW₂

The model will have a specific start and end time and volume (i.e. area and depth of soil). The volume will vary depending on the scale of interest from square metres to paddock to the whole farm or the catchment.

In many situations D and G can be ignored or assumed negligible. Runoff is also often assumed to be zero especially in bay irrigation and controlled application system irrigations.

Daily values of P, I and Et_c are needed. It is also important to have measured soil water values. While daily values might not be available, measurements immediately before and after each irrigation event will minimise the accumulation of errors in the model.

Note that in situations where there is unconfined groundwater (the water table is within a few metres of the ground surface), groundwater can contribute significant water into the root zone of the plant through upward capillary movement (upflow). Water tables within 2 metres of the ground surface can contribute up to 30% or more of the total crop water requirement if conditions are favourable. Ignoring upflow contributions will generally lead to excessive irrigation water being added which in turn will exacerbate shallow groundwater problems.

This then focuses attention on the estimation of Et_c. Most commonly, this is done in a two step process by using the potential evapotranspiration (Et_o) values calculated from weather data appropriate for the location and a crop coefficient (K_c) that is



appropriate for the particular irrigated crop. Currently in Australia a number of methods are used for calculating E_{t_0} (Dodds *et al.*, 2005). Potential E_{t_0} estimates (using the FAO56 calculation method) for anywhere in Australia can be obtained from the SILO website. A wide range of equations have been used to estimate E_{t_0} from meteorological data and no single method is universally adequate under all climatic regimes without some local or regional calibration (Jensen, 1974).

Using FAO56 the E_{t_0} is determined and then multiplied by the appropriate crop coefficient (K_c) to estimate E_{t_c} . K_c values vary between crop species and change as the crop grows. K_c is mostly a reflection of the green leaf area of the crop - the more leaf area relative to the ground area the larger is K_c . Hence when the crop is small, K_c has values around 0.2 to 0.3, as leaf area increases K_c increases and peaks out (often with values between 0.8 and 1.2) when the crop has complete canopy cover and no ground surface can be seen. Table 11 provides some monthly K_c values for crops grown in the Riverina area of southern NSW.

Table 11. Crop coefficients (K_c) of some common annual and perennial irrigated crops for the Riverina area of southern NSW.

	Crop							
	Rice ¹	Maize ²	Wheat ³	Summer pasture	Lucerne	Vines	Citrus	Stone fruit
Jan	1.1	0.9	0.2	0.9	1.3	0.6	0.6	0.8
Feb	1.1	0.9	0.2	0.9	1.3	0.5	0.6	0.8
Mar	1.0	0.6	0.2	0.9	1.2	0.5	0.7	0.8
Apr	0.4	0.3	0.3	0.9	1.2	0.4	0.7	0.8
May	0.2	0.3	0.4	0.8	1.0	0.3	0.7	0.7
Jun	0.2	0.4	0.6	0.8	0.7	0.3	0.7	0.4
Jul	0.2	0.4	0.9	0.8	0.7	0.4	0.7	0.4
Aug	0.3	0.4	1.1	0.8	0.7	0.4	0.7	0.4
Sep	0.4	0.3	1.1	0.8	0.9	0.5	0.7	0.5
Oct	1.0	0.4	0.8	0.9	1.2	0.5	0.6	0.7
Nov	1.1	0.5	0.5	0.9	1.3	0.5	0.6	0.8
Dec	1.1	0.7	0.2	0.9	1.3	0.5	0.6	0.8

¹ Rice sown October, trash retained during winter

² Maize sown November, bare fallow in winter

³ Wheat sown May, trash retained over summer

E_{t_c} can also be estimated using evaporation pans and crop factors which relate crop evapotranspiration to the evaporation measured in the pan (Pruitt, 1966; Doorenbos and Pruitt, 1977). The standard Class A evaporation pan (see Burman *et al.*, 1980) is most widely used and while other pan configurations have been used there is often little consistency between these measures and the more standard approaches.

With the wide availability of reliable weather stations and the ease of calculation of E_t there is little reason to continue with pan evaporation methods that have been plagued with variable and poor maintenance and recording problems.



The main problem with scheduling by water balance is making some assumption of the initial soil water status. Also, errors in both the initial soil water content and E_t estimate can lead to significant errors in the timing and amount of water to apply. These problems can be minimised by actually measuring soil water content and using standard weather data for the location.

5.2.4 *Other considerations – root zone salinity*

As the irrigation industry improves its irrigation practices a new challenge is emerging - salt accumulation in the root zone. In irrigated horticulture, the Lower Murray (Riverland-Sunraysia) region has improved the water use efficiency over the past two decades from about 50% to about 80% as a result of improved irrigation practices. This has had the positive effect of both reducing recharge into groundwater and increasing on-farm water productivity. The reduction in deep drainage also reduces the potential flushing of salts from the root zone to deeper into the profile.

These improvements in irrigation management increase the risk of salt accumulation in the root zone, threatening the sustainability of the region. Irrigation management needs to account for both the crop's needs and additional water (the leaching fraction) to flush salt out of the root zone.

During summer, precision irrigation management results in less than 10% of total applied water moving past the root zone as deep drainage. At 14 surveyed properties the water draining past the root zone had an average leaching efficiency (that is the amount of soil the water actually moves through) of only 65%. All this points to the potential for a build-up of salts in the root zone under the low winter rainfall conditions.

For example, when the average river water salinity is 0.4 dS/m, root zone salinity with a 15% leaching fraction through the whole profile should be about 0.6 dS/m. However, field surveys indicate that the root zone salinity, though very variable, is often greater than 1.3 dS/m because of the inefficiency of salt leaching in these soils.

As irrigation management moves to greater application efficiencies some allowance may need to be considered for leaching of dissolved salts through the soil profile. Currently, in most irrigation systems deep drainage losses are generally far in excess of the leaching fraction required and of greater concern is rising water tables as a result of excessive deep drainage.



Globally, irrigated agriculture leaks water and solutes beyond the root-zone and evidence for this is ubiquitous. In Australia, water leaking beyond the crop root zone or *deep drainage*, is made evident by widespread shallow (<2 m) water tables throughout the major irrigation areas of south-eastern Australia. Deep drainage creates serious problems of water logging and land salinisation. In horticultural areas, such the Murrumbidgee Irrigation Area, Shepparton Irrigation Region and the Riverland along the Murray River, the risk of water logging has been so great that many farms are now protected by expensive (~\$3000/Ha) subsurface drains (or tile drains) that control local water table heights and root-zone salinity.

5.3 Monitoring deep drainage

Irrigation occurs across a wide range of climates, topographies and soil types in Australia. Each location presents a series of minor obstacles to be overcome in order to monitor deep drainage, defined as that water which moves below the root system. However, the first obstacle is the same everywhere – to define the extent of the root system. The maximum vertical extent of this root system must be known in relation to the location of any soil water monitoring device before any conclusions are made about the occurrence or volume of deep drainage. This section therefore begins with a review on the methods of estimating the vertical extent of the root zone.

5.3.1 Root zone extent

There are several ways of obtaining estimates of root zone extent. Here two methods are described:

1. Root sampling by soil pits and soil coring.
2. Soil water monitoring

5.3.1.1 Root sampling

Soil pits are used extensively to examine the properties of the soil with depth. The soil on the face of the excavated hole is carefully removed using a scraper or soil pick to reveal a soil sample that was undamaged during the excavations. This soil is then examined for roots and the root zone extent determined.

Soil coring is performed with a narrow hollow tube that has a cutting edge at the tip. The core is driven with a sledge hammer, electric jackhammer or hydraulic press to depth. The soil core is removed, cut into sections, placed in a medium porosity sieve and the roots removed from the soil by washing with water. Multiple samples are taken at different locations across the irrigation pattern and the root zone extent is mapped. Figure 9 shows a map of the root zone around a grape vine irrigated with drip irrigation in Hanwood, NSW, (Cox, 1995). In this case the density of the roots was estimated by visual assessment of soil



cores. The root zone is offset from the emitter, about 40 cm wide and 60 cm deep.

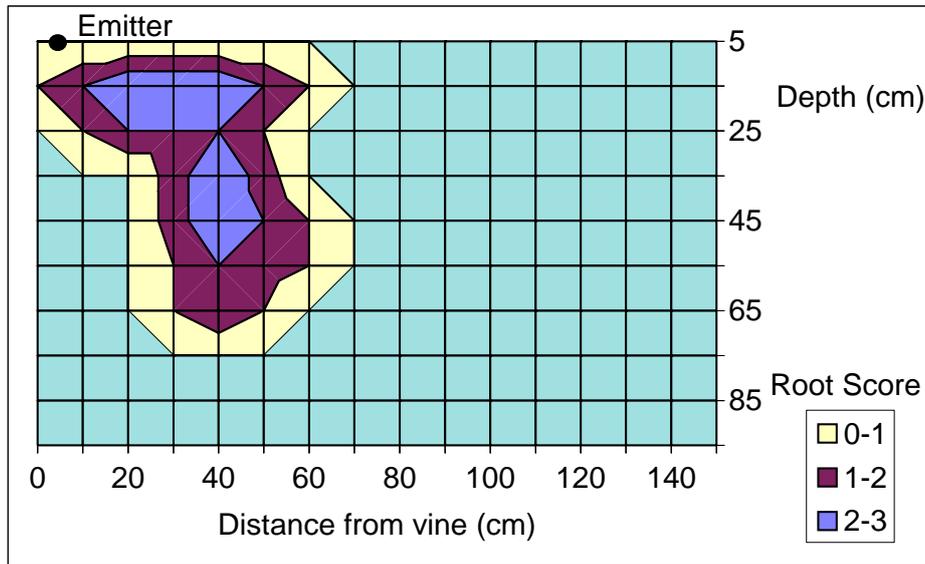


Figure 9. Extent of grapevine root zone with drip irrigation.

5.3.1.2 Soil water monitoring

Soil water sensors can be used to map the root zone extent. Devices such as a neutron probe, profiling capacitance sensors such as *Diviner* (Sentek Pty Ltd), *Gopher* (Sentek) or an array of gypsum blocks such as *GBug* (Measurement Engineering Australia Pty Ltd) require a season of data to determine the zone of water extraction due to the frequency of measurements. However, with the aid of high frequency logged soil water data such as *Enviroscan* (Sentek Pty Ltd) or *C-Probe* (Agrilink Pty Ltd) the root zone extent can be mapped within a few days by observing the diurnal changes in soil water.

The extent of the root zone is identified as the maximum depth where steps of daytime water extraction are visible. Figure 10 shows data collected with an *Enviroscan* soil water sensor. The rooting depth is 70 cm, because the amplitude of the diurnal steps cannot be identified beyond this depth.

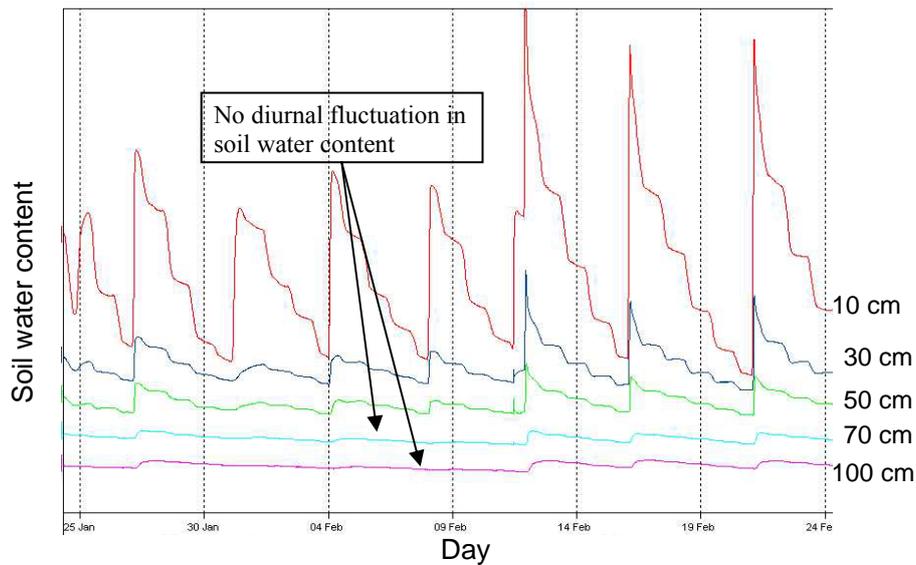


Figure 10. Soil water content from differing soil layers from Enviroscan soil probe.

5.3.2 Deep drainage assessment

Monitoring deep drainage depends on the proximity of the water table to the root system, the level of complexity and the required accuracy. For applications where there is a shallow water table (<2 m), deep drainage is most easily observed by monitoring the water table height in a testwell. Figure 11 shows a testwell installed in a furrow irrigated vineyard in Griffith. A 3 m long PVC tube is slotted for its full length, covered with a fine mesh sock and installed in a vertical hole in the soil.



Figure 11. Testwell in vineyard with capacitance logger



The water level in the testwell follows the rise and fall of the water table in the soil. This data can be measured manually with a plopping bell or recorded with water level sensor. The volume of deep drainage is given approximately by the height of the water table rise multiplied by the Air-Filled Porosity (AFP) of the soil above the water table. A typical set of data for a furrow irrigated vineyard, where the average air filled porosity was measured to be 4% between 60 and 200 cm, is shown in figure 12 (Christen and Skehan, 2000).

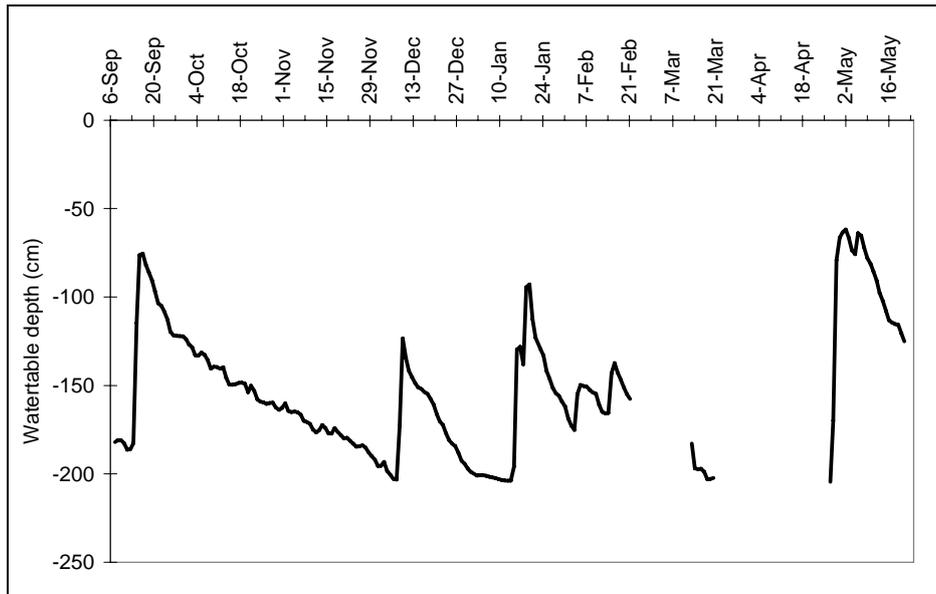


Figure 12. Water tables under furrow irrigated vineyard in MIA.

This data shows that before the irrigation season the water table was at ~180cm. After the first irrigation (16th Sept) it rose to a depth of 75 cm. Thus, for this event deep drainage was about 42 mm (change in water table height × AFP; 1050 mm × 0.04). The water tables then declined rapidly to about 130 cm. The second irrigation on the 8th December caused a 70 cm rise in water table height which produced deep drainage of 28 mm, and so on for the other water table rises. The total deep drainage for this irrigation period is estimated to be 172 mm.

For tile drained paddocks deep drainage can be monitored by recording the flow of water from the pump that lifts the water from the tile drain sump. In general, tile drains intercept a regional flow and deep drainage from irrigation and rainfall. The base flow and deep drainage flows are distinguished in the record by a separation in time scale. Figure 13 shows a typical flow record of tile drain flow for a furrow irrigated vineyard in Griffith. Deep drainage is given approximately as the volumetric flow rate of the pump divided by the irrigated area.

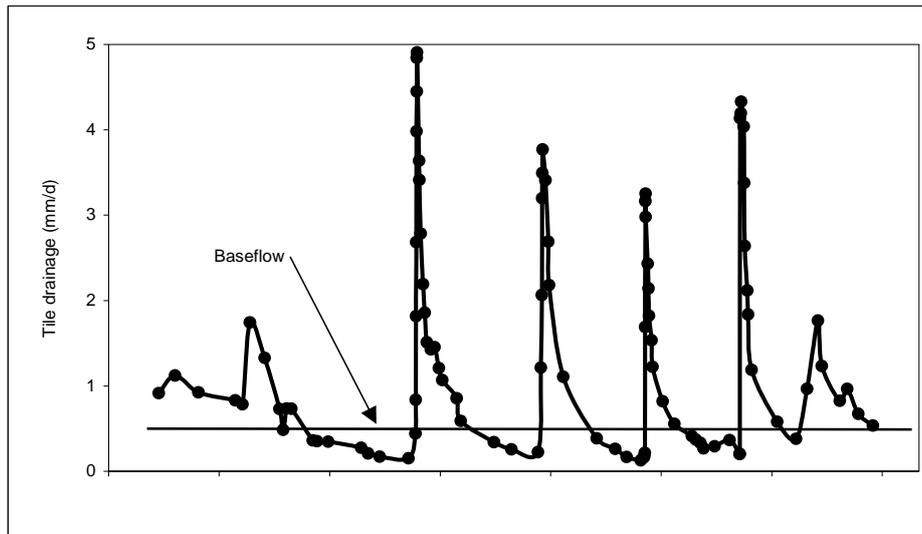


Figure 13. Tile drainage flow in furrow irrigated vineyard.

When water tables are deep, testwells are not useful for monitoring deep drainage because there is a long lag and a damped response between the irrigation event and water table movement. In this case a soil water sensor placed beneath the root system is most useful. This will give information about the timing and duration of deep drainage but not the actual volume.

Deep drainage can be monitored using soil water sensors which measure either volumetric water content or soil water potential. However, soil water potential (or soil tension) devices are superior because they are more sensitive to small changes in deep drainage. In general, a rapidly draining soil has a soil water potential greater than -10 kPa. To monitor deep drainage, tensiometers such as the *Watermark* (Irrometer Inc.), *Jet-fill* (Irrometer Inc.), *Soil-Spec* (H&TS Electronics Australia Pty Ltd) or *Tube Tensiometer* (Hutchinson and Bond, 2001) are buried beneath the root zone. Figure 14 shows a record of the soil water potential at a depth of 75 cm beneath a furrow irrigated vineyard in Griffith measured with a *WaterMark*. Periods of deep drainage follow immediately after irrigation and water logging occurs for a few days.

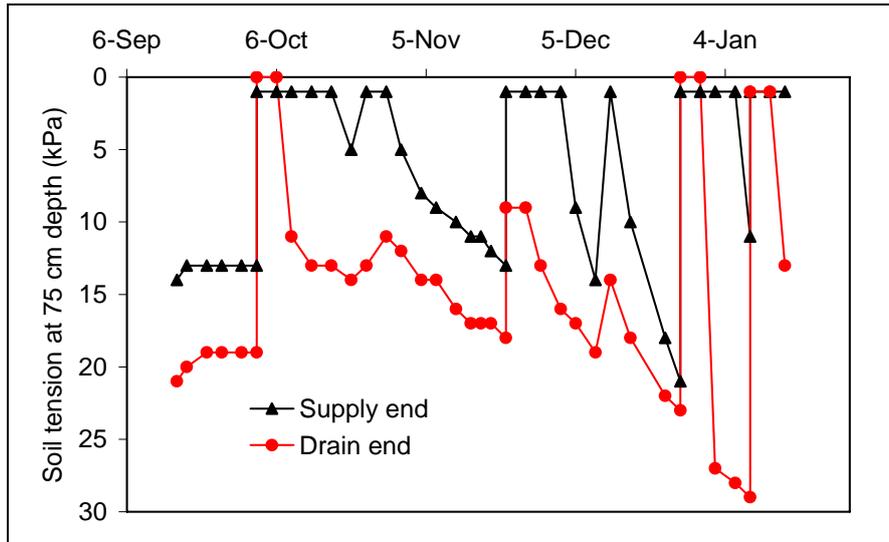


Figure 14. Soil water potential at 75 cm, beneath a young vineyard.

To estimate the actual volume of deep drainage from tensiometer data, a pair of tensiometers are spaced apart vertically and the hydraulic gradient is measured. This gradient is then multiplied by the soil hydraulic conductivity at the location of the tensiometers. This is a research technique.

A more recent method of determining deep drainage has been the development of drainage lysimeters (McGarry, *et al.*, 2006). These drainage lysimeters have been installed in a range of soils growing cotton under surface irrigation. Preliminary results indicate deep drainage of approximately 100 mm (i.e. 1 ML/ha/year) under cotton irrigated with 5-6 ML/ha/year.

5.3.3 Characteristics of deep drainage

5.3.3.1 Timing

Evidence of deep drainage has been collected from bay, furrow and drip irrigated situations. Some generalisations are:

1. Deep drainage is often greatest in spring as canopies are not fully developed, evapotranspiration is low and the soil profile is wet with winter rainfall.
2. Rainfall after early season irrigation contributes to significant drainage in spring.
3. In summer the canopy develops and there is less drainage because the majority of the applied water is being transpired.
4. Rainfall has less impact on deep drainage during summer.



5.3.3.2 Irrigation system

Irrigation method has shown to play a major role in deep drainage. Leakiness is reduced when bay and furrow irrigation layout is improved by reducing row length, changing furrow shape and increasing flow rate. Drip irrigation reduces the risk of deep drainage because small volumes of water can be applied so that small water deficits can be managed. However, under drip irrigation there is still deep drainage because the ability of the soil to move water horizontally can be overestimated by the irrigation designer and irrigator. This is particularly true of soils like sands and heavy clays.

Changing irrigation systems - reducing drainage

Peter, through changing his irrigation method and introducing some objective irrigation scheduling dramatically reduced his drainage. By improving the irrigation management and tile drainage management the total amount of tile drainage from the vineyard was reduced by 88%. The quantity of salt removed by the tile drainage system was also reduced, but still adequate to control root zone salinity. This has the potential to reduce salt loads to downstream environments if drainage water flows into channels and streams.

Case study 1.1.8

A comparison of three vineyards using bay, furrow and drip in the MIA was undertaken by Christen and Skehan (2000). All three vineyards were monitored for irrigation applied, subsurface drainage, run-off and water tables for the 1995/96 season (Table 12). Drip irrigation gave greater control over irrigation applications, using small amounts of water that were applied frequently. This resulted in no run-off or tile drainage from irrigation. In comparison, in bay and furrow irrigation run-off and drainage fluctuates widely, demonstrating the difficulty of getting good control of surface water.

Table 12. Summary of irrigation system performance (Christen and Skehan, 2000).

System	Number of irrigations	Water applied (mm**)	Run-off from irrigation (mm)	Tile drainage from irrigation (mm)	Percentage tile drained (%)
Bay	10	355	13	52	15
Furrow	6	385	41	37	10
Drip*	26	140*	0	0	0

* The drip irrigated vines were only 2 years old, thus reduced water use would be partly due to reduced Et,

** About 200mm of in season rainfall is not included in these figures



Only drip irrigation prevented surface runoff. This was clearly demonstrated when 65 mm of rain fell in 24 hours, resulting in only 1.5 mm of run-off, the rest of the rainfall being absorbed in the dry inter-row area.



6 Technology trends and future directions in irrigation decision making

Currently irrigators have a number of technologies and information sources available for irrigation decision making. Conventional measurements have been discussed in previous chapters. This chapter outlines future directions in irrigation technology and information sources for improving irrigation decisions.

Traditionally tools for irrigation decision making have been focused around localised point source measurements. These have included both plant and soil based measurements with the latter being the most popular. In the past 10 years there have been significant advances made in the development of technologies for measuring larger spatial information patterns such as various remote sensing platforms and portable, GPS-referenced sensing devices attached to farm and irrigation machinery. While uptake and use of these spatial information sources has been relatively low, one of the major barriers has been the ability both to visualise this information and to put it into a format which assists in decision making. Indeed these tools and technologies have largely remained in the realm of the scientific community.

Advancements in visualisation technologies and frameworks or platforms for visualising spatial information have undertaken an exponential increase in the last three years. To quote from one of the world's leading Geographic Information System (GIS) experts, Michael Goodchild, a GIS expert at the University of California, Santa Barbara, "Typically, I used to spend an entire year taking senior undergraduates through courses in GIS. And at the end of the year, as a treat, I might let them generate a three-dimensional fly-by over a landscape," he says. "Now, using GoogleEarth, a ten-year old can do that." These advancements offer the ability for non-GIS experts such as irrigators to begin to harness these technologies in irrigation decision making.

The following sections outline potential benefits, systems and current state of the art examples in which various non-traditional sources of information are being used to assist in irrigation decision making.

6.1 Limitations of traditional information sources

6.1.1 *Common approaches*

The two most widely adopted irrigated information tools for assisting irrigators to make decisions regarding irrigation have been soil water monitoring and evapotranspiration (Et) measurements. Traditionally the majority of decisions regarding when to irrigate have focused on these



two methods. While soil water monitoring has been used and is a valuable tool, it lacks the ability to fully incorporate the spatial variability which is common throughout an irrigated field and farm. Coverage of areas using soil water probes is generally well under 6% of the area and the high cost, either directly upfront for wireless based systems, or indirectly through manual collection of information, limits the spatial coverage of soil water based systems.

Et scheduling, through the use of weather data collected locally by a reference E_t station, suffers from the drawback that crop coefficients vary widely, dependent upon the irrigation and crop management. Indeed, for many of the currently irrigated crops and irrigation management regimes information to describe crop coefficient development adequately through the growing season does not exist. Crop coefficients can, of course, be generated and refined but only if measurements are made of water applied, soil water change and crop canopy development.

Therefore, while these traditionally dominant tools for assisting with irrigation scheduling are extremely useful they also have the potential to be incorporated with other technologies which significantly value add to this information.

6.1.2 Decisions in isolation

In real world situations irrigation decisions are rarely based on one information source. Indeed a farmer may consider a number of information sources for basing decisions on when and how to irrigate. Unfortunately, the large majority of irrigation support tools currently in operation tend to focus on providing only one source of information and rarely offer an integrated package. This is particularly evident when examining the summary of Australian software tools for on-farm water management (Inman-Bamber and Attard, 2005). While a number of excellent tools have been developed for assisting with irrigation decision making they have generally focused on one aspect i.e. soil water monitoring or E_t water balance scheduling. This limits the value and amount of information which is available for making decisions. For example, when considering soil water monitoring, knowledge of the current estimated rainfall through radar provides useful information which the soil water information software package may not be able to provide.

At the next level, an economic cost associated with that decision, based on a simple model or relationship, provides an even greater insight into the consequences.

Therefore, one of the limitations of traditional approaches to irrigation decision making has been the difficulty of incorporating various information sources and value-adding knowledge in a coherent, easy to use and easy to understand framework.



6.2 Creating systems and information management frameworks

Currently there are a number of information sources: databases, on-site measurements, remotely-measured information and various concepts, knowledge and science that can help assist in irrigation management. Examples include, but are not limited to: SILO, E_t_0 calculation procedures, use of crop factors to estimate water use, NDVI data, yield mapping, water accounting software and field data such as soil water sensors and weather stations and satellite and radar images. These various elements need to be brought together to provide better irrigation management and water use estimates to irrigators and water providers. This information also has to be delivered in the most useful way e.g. via the web, to a mobile phone or directly to an irrigation controller.

The CRC for Irrigation Futures is investigating methodologies and tools through the study of Irrigation InformaticsTM. The amount of information generated relating to irrigation is increasing exponentially, however harvesting and making use of this information has often been difficult in an irrigation decision making context. Irrigation Informatics involves developing the science of storage, retrieval, and optimal use of biophysical information, data, and knowledge for problem solving and decision making in irrigation management. The objectives of Irrigation Informatics are to:

- Provide a water management information and accounting framework to guide irrigation decisions
- Integrate remote sensed and field data with water accounting to determine crop water use
- Provide spatial estimates and accounting of crop water use from field to regional scales
- Provide spatial estimates and accounting of drainage below the root zone from field to regional scale
- Develop low cost, frequent estimates of water use at regional scale for use by bulk water providers
- Develop spatial estimates of water use at the field scale to guide irrigation and agronomic decisions.

From an end-user perspective as an irrigator, Irrigation Informatics aims to offer an integration of the various information sources and relationships in an easy to use end product which may take on various forms. For example, actual predicted soil water levels may be delivered to an irrigator through a graphical spatial display on a mobile phone at daily intervals which have been generated from a combination of remote sensed NDVI vegetation indexes, current soil water data from probes and forecasted weather data (Figure 15).

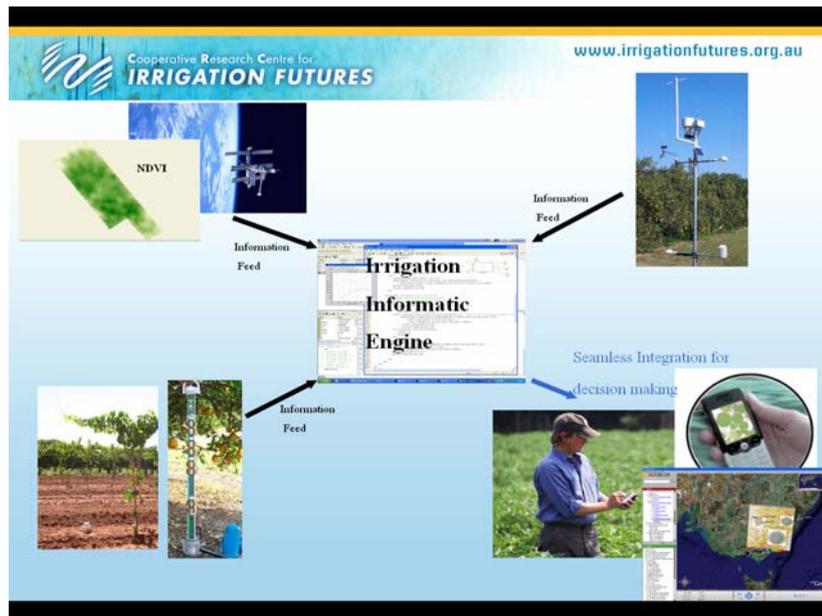


Figure 15. Irrigation Informatics™

In order to highlight the feasibility of such approaches two examples from the United States and Europe are described below which are incorporating a number of information sources, ranging from on-ground measures to satellite images, for assisting in providing information for better decisions on irrigation.

6.2.1 Irrigated wine grapes in California USA

In California the potential of using remotely based information sources combined with localised irrigation technologies was evaluated (Johnson *et al.*, 2006). During the 2005 irrigation season a field based test trialed a system for providing ‘nowcasts’ and forecasts of irrigation critical information using a combination of satellite images with a 4×4 m resolution and ground based E_t_0 reference station networks. These were combined with a soil water balance model and used to generate critical irrigation information such as soil water content, crop water stress and irrigation demand.

The automated system streamlines data retrieval from the various information sources, pre-processing, integration, and soil water balance modelling and produces daily spatial coverages of leaf area index, soil water content, leaf water potential, cumulative applied irrigation and cumulative water stress. Weather forecast information could also be used in the system to specify irrigation recommendations based on water stress levels of the vine. The developed information system provided daily spatial coverages (such as those shown in Figure 16) to irrigators. These were available for viewing on the web by 9:00am each morning. For a full description of the system refer to Johnson *et al.*, (2006).

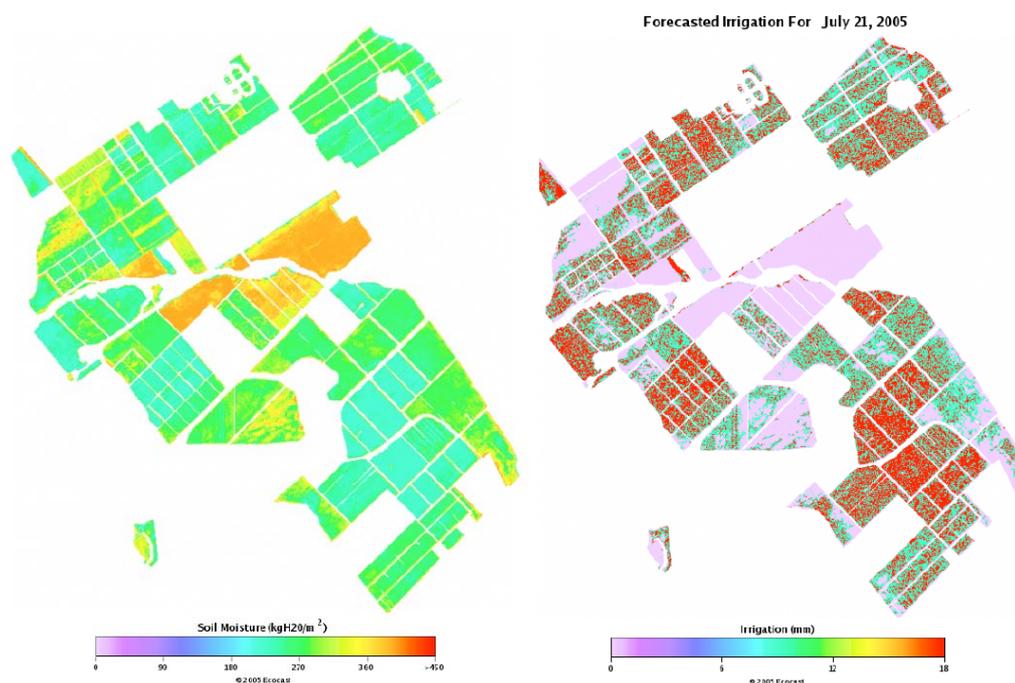


Figure 16. Soil water and forecast irrigation for a 400 ha Napa Valley irrigated vineyard. Further images and seasonal information is available from <http://ecocast.arc.nasa.gov/images/html/napa/index.html> (Johnson *et al.*, 2006).

6.2.2 DEMETER in Europe

The DEMETER (DEMONstration of Earth observation TEchnologies in Routine irrigation advisory services) project which has been undertaken in Europe aims at assessing and demonstrating how the performance and cost effectiveness of irrigation advisory services can be substantially improved by the incorporation of Earth observation techniques and Information Technology (IT) into their day-to-day operations (Belmonte *et al.*, 2003). The authors cross-referenced satellite platforms to provide better temporal resolution of coverage of the study regions. Algorithms were then developed to relate crop coefficients to Normalised Difference Vegetation Index (NDVI) (Figure 17) which, when combined with traditional on-ground ET_0 reference stations could be used for spatially estimating water use of irrigated crops. This information was then delivered to irrigators through multimedia message service features on mobile phones.

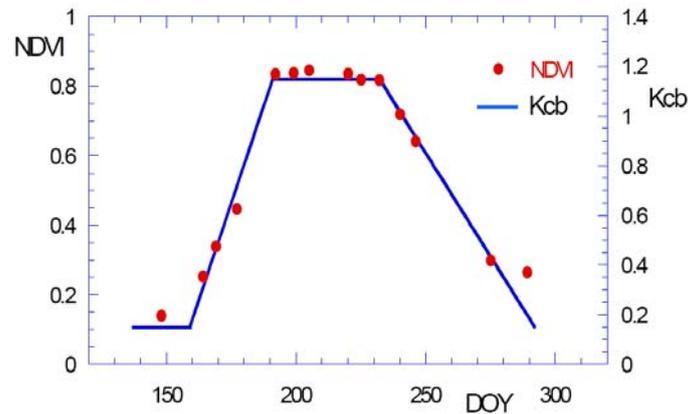


Figure 17. Temporal evolution of crop coefficient K_{cb} and of NDVI in maize during 2001 growing season after (Belmonte *et al.*, 2003).

These two examples show the possibilities associated with incorporating non-traditional information sources (in these cases remotely sensed vegetation indices) into irrigation decision management to value-add to traditional information sources, such as E_t , weather station information. Such systems offer the irrigator a powerful tool for making irrigation decisions and are focused on providing an end-user product tailored to irrigators.

Extensions of this approach include Irrigation Informatics systems which also track other decision variables, such as current price of water, current price of produce (which can be updated daily), current input costs, and predicted resource availability (i.e. water). A prototype conceptual Irrigation Informatics system which has been incorporated in the Google Earth application is shown in Figure 18. It provides spatial coverage of irrigated soil information, and routinely updated weather radar information, seven day weather forecast, updated soil water information from wireless soil water probes which store the information on the web, current price of water, current dam levels for two major storages and current price of produce. Once setup, the irrigator accesses the information by clicking the required 'checkboxes' to display this information in one application.

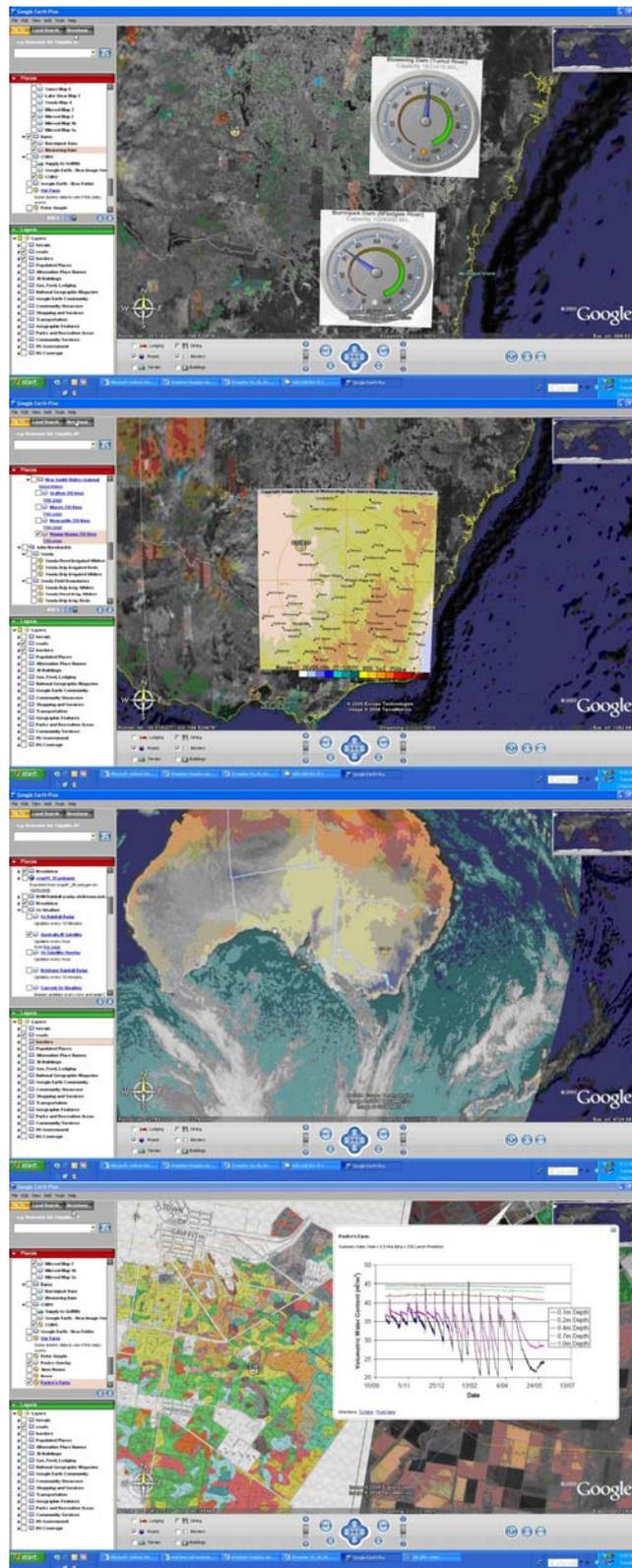


Figure 18. Prototype conceptual Irrigation Informatics system which has been incorporated in the Google Earth application showing (from top to bottom) a spatial soil property map, current water supply levels, weather radar, satellite cloud cover and soil water which are automatically updated from the web.



The potential to harness non-traditional information sources has increased dramatically in the last few years. High resolution satellite imagery has become freely available and is already being used qualitatively by irrigators. Information systems for spatial data have dramatically advanced in their ease of use as evidenced by the estimated 12 million users worldwide of Google Earth. These factors, when combined with the necessary understanding of relationships and drivers of water use efficiency, have the potential to significantly improve the way irrigators make decisions and the information sources they use to do this. The examples described in this chapter provide an insight into the future trends in technology related to irrigation management and how they are being utilised.



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