AQUALINC RESEARCH LIMITED

Irrigation Efficiency Gaps
- Review and Stock Take

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and
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IRRIGATION NEW ZEALAND INC

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EXECUTIVE SUMMARY

With increasing demand on the water resources, irrigation efficiency is becoming one of the key issues facing irrigation farmers and water managers in New Zealand.

There are many benefits to improving irrigation efficiency, including both environmental and economic. These include less stress on water resources, reduced losses of water and nutrients to groundwater and surface water resources, improving production and overall profits; and potentially allowing a greater area to be irrigated with a given volume of water.

Irrigation efficiency can be defined in many different ways, with over 30 definitions currently in use. Efficient on-farm irrigation depends on water use, energy use, labour and capital investment, and how these aspects relate to production and profitability, and there is no single definition that covers all aspects of irrigation efficiency.

Irrigation efficiency depends primarily on the hydrological boundary used – paddock, district, catchment or region, the timeframe – one application or over an irrigation season, whether the volume of water taken from source is beneficially used, soil water storage and effective use of rainfall and all uses within an area.

Sustainable Farming Fund (SFF) requested that Irrigation New Zealand (INZ) conduct a project to summarise the following:

- Expectations and views on irrigation efficiency;
- The state of the knowledge on irrigation efficiency;
- Identify the gaps in knowledge; and
- Decide what further work is required, including communication and education.

A previous report (McIndoe, *et al.,* 2005) summarises the expectations and views on irrigation efficiency from a range of people and organisations.

The scope of this report is to carry out a literature review to establish the state of knowledge on irrigation efficiency and to help identify gaps in that knowledge.

A workshop was proposed to discuss the information present in the two reports, to further quantify gaps in knowledge and to develop strategies for the way forward. This workshop was held in August 2005.

The review of existing information found that, although there are many definitions of irrigation efficiency, they can be grouped into three main categories of irrigation efficiency, application efficiency and distribution efficiency.

In general, irrigation efficiency is related to the percentage of water delivered to the field that is used beneficially. Because the benefits of applying water are not immediately attained, definitions containing a measure of beneficial use are usually applied over a longer timeframe than for individual events. These definitions are more relevant when considering seasonal water allocation or seasonal water use.

Where the focus is on the performance of a single event, application efficiency (AE), which is the most common understanding of the meaning of irrigation efficiency, is used. In broad terms, application efficiency is the percentage of water delivered to the field that is used by the crop.

Distribution efficiency, which is a measure of uneven application, is usually defined in terms of distribution uniformity and has a significant effect on application efficiency. It is usually determined by measuring the depth of water falling into a grid of catch cans during an irrigation event and analysing the variation of water depths in the catch cans.

The value of a particular definition depends on the viewpoint of the author and the context of the hydrological boundary used, beneficial use, soil water storage and effective use of rainfall. Very "efficient" systems by some definitions can be very poor performers by other definitions.

Verifiable information on application efficiencies measured under New Zealand conditions is becoming readily available as more research projects have been completed. Internationally, several US universities have published application efficiencies for a range of irrigation system types.

Significant variation in application efficiencies was found to occur in all investigations carried out in New Zealand and internationally. Application efficiency varies with every irrigation event, depending on how the water is applied and the conditions existing at the time of the irrigation event and is therefore an output arising from a sequence of events. A particular value is not something that can be assumed to occur for all irrigation events.

The research found that most irrigation system types could be designed to operate efficiently, including surface irrigation methods such as border-strip irrigation. However, not all irrigation systems are designed to have high application efficiency. If it can be shown that there is no significant disadvantage to the environment or to other users in having lower application efficiency or if modifying a system may make it uneconomic or unworkable, lower application efficiency may be desirable.

The key factors that influence irrigation efficiency are how well the system is designed and how well the system is managed. The design of the system is crucial for the future operation and management of the irrigation system and the potential for efficient irrigation. With poor design, attainable irrigation efficiency will be low, regardless of the standard of system management. With good design, high efficiency will be attainable, but whether it is achieved or not still depends on how well the system is managed.

The main losses within an irrigation system are due to uneven/excessive application depths and are therefore the areas with the greatest potential for improvements in efficiency. Excessive application is largely due to inflexible design or is a management issue. Uneven application usually results from poor distribution uniformity (wind or by substandard sprinkler distribution patterns), or by excessive application rates causing surface redistribution.

Also critical to achieving high efficiency is having access to a reliable water supply, so that water can be used when it is needed rather than when it is available. Although having access to a reliable water supply is usually an economic or engineering issue, its importance is often understated, and further effort needs to be put into improving the reliability of water supply systems and providing water on demand if efficient irrigation is to be achieved on a broader scale.

Several organizations have initiated projects to carry out and collate recent research and current knowledge about irrigation design and management. Many of these are community projects have been funded through AgMardt or through the MAF Water Fund or Sustainable Farming Fund. The information from the projects has been presented in the form of irrigation handbooks or other handouts, which have been made available to farmers and are valuable reference sources for anyone involved in irrigation or irrigation related activities.

Currently, there are no performance standards or codes of practice for irrigation system design in New Zealand. INZ, as part of its charter to promote economically and environmentally sustainable irrigation, has taken a proactive step and initiated the development of irrigation system design performance standards and a code of practice. Development of the code has been financially supported by MAF Sustainable Farming Fund (Grant 02-079).

In parallel to the Irrigation Design Code of Practice, a Code of Practice for On-Farm Irrigation Evaluation (SFF grant 02/051) has been developed to provide guidelines for people undertaking evaluations of irrigation systems in the field. It makes specific recommendations for planning and conducting evaluations and reporting on the performance of irrigation systems and their management.

Measuring water use and soil moisture is crucial for calculating irrigation efficiency. Until recently, very little water use measurement and soil moisture monitoring has occurred. Progressively more irrigators are implementing water use measurement and soil moisture monitoring to improve irrigation management, but there are still many farmers not routinely measuring irrigation water use or soil moisture.

Today, water meters are usually required to satisfy conditions of consents to take and use water. Soil moisture measurement is one of the best methods of providing information to farmers to enable them to manage irrigation applications to achieve both high application efficiency (providing the irrigation system has that capability) and high water use efficiency. Soil moisture measurement technology has improved significantly over recent years, with a wide range of devices and methods now available.

Although reducing capital and operational costs and irrigating efficiently will help maximise returns, the cost of water in the past has been considered reasonably low, providing little value/incentive to improve efficiency on the basis of the cost of water alone. More recently, there has been a shift to the installation of more efficient systems and improvements to existing systems. This is partly attributable to increasing energy costs, particularly with many spray irrigation systems and implies that costs are now starting to drive the change towards more efficient irrigation.

Another driver of more efficient systems is the ability to produce more output with greater reliability in water short areas. Higher efficiencies are also enabling water to be applied over larger areas, particularly within irrigation schemes.

The initial capital cost of irrigation systems is a key deciding factor in the choice of irrigation systems, but there is now greater awareness of the importance of on-going operating costs, particularly pumping costs, maintenance costs and labour costs, than was the case in the past. More farmers now realise that initial higher capital investment will be returned through improved management and performance of the system.

Despite the obvious benefits of more efficient systems, designing a system that is 100% efficient, although technically possible, may not be financially viable and it is important to strike a balance between application efficiency and other interacting factors such as capital cost, operational cost and labour.

Several projects have been completed that have investigated the potential savings in energy that could be obtained through more efficient irrigation design or management and concluded that substantial savings could be made. Pumping was the main user of energy and systems that require little or no pumping such as efficiently-designed border-strip systems may compare favourably to spray irrigation systems, when energy is included in efficiency assessments. Potentially, through improved well construction and development, energy requirements for pumping could be reduced. However, the relationship between well performance and well construction is poorly understood and requires further research.

Although the cost, availability and reliability of labour for irrigation has become a significant issue, very little formal investigation into the labour requirements of operating irrigation systems has been carried out. Further work needs to be carried out to determine the relationship between labour requirements, capital expenditure (replacing labour with capital) and the impact on irrigation application efficiency and production.

Unreliable water supplies impact significantly on the efficiency of on-farm irrigation systems and off-farm irrigation schemes. Inefficiency arises from system operators minimizing the risk of water supply restrictions whether they are caused by environmental limits (minimum flows for example) or by infrastructural restrictions such as fixed roster periods. Further emphasis needs to be given to improving water supply reliability if irrigation efficiency is to be substantially improved on many schemes.

The most inexpensive form of water application is rainfall, so it is logical to make as much use of rainfall as possible to meet crop needs. It is possible to have high irrigation application efficiency but low rainfall application efficiency. By improving the reliability of water supplies and irrigation systems, it is possible to make more use of rainfall, thereby minimising water takes and drainage to groundwater.

In terms of gaps in knowledge, a significant amount of knowledge about current irrigation practices and the measures required to improve irrigation efficiency exists, but has not been well-transferred to the general public or practitioners in the field. The biggest gap therefore, is communicating the knowledge to stakeholders.

There appears to be further opportunity to improve efficient use of water through measuring actual water use and measuring soil moisture

Better understanding needs to be gained about the relationship between water application, energy use, labour and capital expenditure when quantifying irrigation efficiency in the wider context. The wider benefits of using one particular irrigation method versus another have not been well quantified.

The impact of irrigation application rates exceeding soil infiltration rates, causing surface redistribution and potential runoff, and how that impacts on crop production is not well understood.

There are also gaps in our knowledge of well performance and well efficiency and in particular how to construct wells to maximise well efficiency.

1 INTRODUCTION

1.1 Background

Irrigation efficiency is becoming one of the key issues facing irrigation farmers and water managers in New Zealand. With increasing demand on water resources, it is becoming more important to manage these resources effectively. Generally, the wider New Zealand community is much more environmentally aware than in the past and sees inefficient water use as a threat to water resource sustainability. To maintain access to water, there will be more pressure on farmers to demonstrate that they are using water effectively and efficiently.

There are many benefits to improving irrigation efficiency, including both environmental and economic. Improving irrigation efficiency will:

- Mean less stress on water resources, less losses of water and nutrients to groundwater and surface water resources;
- Minimise irrigation inputs while continuing to maintain/improve production and overall profits;
- Potentially allow a greater area to be irrigated with a given volume of water.

The key is to irrigate efficiently to improve economic performance (improving on-farm productivity) and environmental performance (reducing impacts on water source and receiving waters) in a complementary way. This in turn will also improve overall public perception as well.

Irrigation efficiency can be defined in many different ways depending on the perspective that is considered. In fact there are over 30 different definitions in use.

Key points that need to be considered with irrigation efficiency are:

- The definition of the hydrological boundary – paddock, farm, district or region
- The timeframe – a single event or multiple events over an irrigation season
- Whether the volume of water taken from source is beneficially used.
- Water stored in the soil and effective use of rainfall
- All uses within an area

Efficient on-farm irrigation depends on water use, energy use, labour and capital investment and how these aspects relate to production and profitability. There is no single definition that covers all aspects of irrigation efficiency. The level of efficiency that can be attained is a compromise between many factors.

1.2 Scope

Sustainable Farming Fund (SFF) requested that Irrigation New Zealand (INZ) conduct a project to summarise the following:

- Expectations and views on irrigation efficiency
- The state of the knowledge on irrigation efficiency
- Identify the gaps in knowledge
- Decide what further work is required, including communication and education.

INZ has engaged Aqualinc Research Ltd, Tony Davoren (Hydro Services Ltd) and Dan Bloomer (Page Bloomer Associates Ltd) to carry out the work.

In Report L05264/1 (McIndoe *et al.*, 2005) the views and expectations from a range of people and organisations on irrigation efficiency were summarised. The scope of this report is to carry out a literature review to establish the state of knowledge on irrigation efficiency and to help identify gaps in that knowledge.

A workshop was proposed to discuss the information present in the two reports, to further quantify gaps in knowledge and to develop strategies for the way forward.

1.3 Objectives

The objectives for this report are to:

- Determine what is already known about irrigation efficiency
- Describe the interaction of other factors that may affect irrigation design and efficiency, including:
  - economics and use of capital
  - energy and labour
  - scale of system that is considered (paddock versus farm versus district)

2 EXISTING KNOWLEDGE ON IRRIGATION EFFICIENCY

A review has been completed on the information that already exists on irrigation efficiency.

2.1 Irrigation Efficiency Definitions

Although there are many definitions of irrigation efficiency, they can be grouped into three main categories of irrigation efficiency, application efficiency and distribution efficiency.

The following summary of irrigation efficiency, application efficiency and distribution efficiency has been sourced from McIndoe (2002).

2.1.1 Irrigation Efficiency

In general, irrigation efficiency is related to the percentage of water delivered to the field that is used beneficially. Because the benefits of applying water are not immediately attained, definitions containing a measure of beneficial use are usually applied over a longer timeframe than for individual events. These definitions are more relevant when considering seasonal water allocation or seasonal water use.

The traditional definition of irrigation efficiency (IE) (from ASCE, 1978) is:

$$IE = \frac{\textit{Volume of water beneficially used}}{\textit{Volume of water delivered to field}} \qquad (1)$$

Burt *et al.* (1997) modified this definition to account for soil-water storage as:

$$IE = \frac{\textit{Volume of irrigation water beneficially used}}{\textit{Vol of irrig water applied – Change in storage of irrig water}} \qquad (2)$$

This definition considers the overall water balance, area, hydrological boundaries, rainfall, soil moisture storage, and all uses over an appropriate timeframe.

The approach developed by the International Commission on Irrigation and Drainage (ICID) by Bos *et al.* (1993) and adopted by the Australian Irrigation Association (IAA) provides the following overall definition of irrigation efficiency. They use the term overall project efficiency, which is suitable for all irrigation systems and is defined as follows:

$$OPE = \frac{\textit{Crop water use}}{\textit{Total inflow into supply system}} \qquad (3)$$

Bos *et al.* subdivided this definition into three sub-components – *conveyance efficiency*, *distribution efficiency* and *field application efficiency*, to track and account for water use from the point of supply through to the crop.

Because of the many factors that influence irrigation efficiency from the source to the crop (capital investment, labour availability and skills, energy use, weather, and the physical performance of irrigation systems), focusing on attaining a reasonable level of irrigation efficiency may be more realistic than trying to calculate irrigation efficiency rigorously. This takes the focus off trying to define all aspects of beneficial use. Burt & Styles (1994) have used an alternative definition that they have called irrigation sagacity (IS), which they consider to be a better measure of wise water use than irrigation efficiency, as follows:

$$IS = \frac{\textit{Irrigation water beneficially or reasonably used}}{\textit{Irrigation water applied}} \qquad (4)$$

Although this definition is probably a better measure of good water use, it has not been widely adopted, primarily because of the difficulty of measuring beneficial or reasonable use.

One useful measure of irrigation efficiency that encompasses both water use and production is water use efficiency (WUE). It is commonly defined as:

$$WUE\ (kg/m^3) = \frac{Production\ (kg/ha)}{Irrigation\ water\ use\ (m^3/ha)} \qquad (5)$$

Until recently, this definition was not often considered as a measure of irrigation efficiency in New Zealand, although it is commonly used in Australia and the USA.

Water use efficiency (WUE) was identified as one of the key water use indicators derived in a study of indicators of sustainable irrigated agriculture (LE, 1997), and is of most benefit to individual farmers. The definition focuses farmer's attention on both water use and production, and provides an indication of whether the resource has been used effectively.

This definition has also used when conducting design audits for both Ida Valley – Central Otago (LE, 2005) and the Hawke's Bay regions (McIndoe, 2000).

An alternative definition of irrigation efficiency that takes into account the seasonal nature of irrigation is seasonal irrigation efficiency (SIE), which was developed as part of the development of indicators of sustainable irrigation (LE, 1997; Wells & Barber, 1998). It relates the depth of water applied in a season to consumptive use of the crop as follows:

$$SIE = \frac{Seasonal\ depth\ of\ water\ applied\ to\ crop}{Seasonal\ evapotranspiration - Seasonal\ rainfall} \qquad (6)$$

This definition typically gives values in the range of 1-2, with the more efficient systems resulting in values closer to 1.

2.1.2 Application Efficiency

Where the focus is on the performance of a single event, application efficiency (AE) is most commonly used. In broad terms, application efficiency is the percentage of water delivered to the field that is used by the crop. The typical definition (e.g. Bos & Nugteren, 1974; ASCE, 1978; Jensen *et al.*, 1983; Walker & Skogerboe, 1987) is known as water application efficiency (WAE) and is:

$$WAE = \frac{Volume\ of\ water\ required\ to\ replace\ crop\ evapotranspiration}{Volume\ of\ water\ delivered\ to\ the\ field} \qquad (7)$$

Burt *et al.* (1997) define irrigation application efficiency (IAE) as follows:

$$IAE = \frac{Average\ depth\ of\ irrigation\ water\ contributing\ to\ target}{Average\ depth\ of\ irrigation\ water\ applied} \qquad (8)$$

Burt's definition differs from the one typically used as it goes beyond simply replacing soil water deficits. It implies that water contributing to the target will eventually be beneficially used. In addition to meeting ET, it considers crop water needs such as germination, cooling, frost protection, leaching (limited requirement in New Zealand) and pest control. Partial replacement of the soil water deficit to allow more effective use of rainfall is also considered.

The definition proposed by Bos *et al.* (1993) for field application efficiency (FAE) is:

$$FAE = \frac{\text{Water applied that is used by crop}}{\text{Water delivered to irrigation field}} \qquad (9)$$

Another common definition relating to application efficiency is irrigation system efficiency (ISE), as defined by Painter & Carran (1978):

$$ISE = \frac{\text{Water applied that is stored in crop root zone}}{\text{Total amount of water delivered to the farm}} \qquad (10)$$

Commonly, a variation to the above definition is used:

$$AE = \frac{\text{Water applied that is stored in crop root zone}}{\text{Average depth of water applied to crop}} \qquad (11)$$

This is identical to definition 10 for most piped sprinkler irrigation systems, where losses between the water delivery point and the field are negligible. It will differ on systems utilising non-piped delivery methods, as frequently found on border-strip irrigation systems.

This definition has been used when conducting design evaluations for both Ida Valley – Central Otago (LE, 2005) and the Hawke's Bay regions (McIndoe, 2000). This definition was also adopted in the study prepared for the Ashburton Lyndhurst Irrigation Society "Field proven irrigation efficiency benchmarks" (Rout, *et al.*, 2002)

2.1.3 Distribution Efficiency

Distribution efficiency, which is a measure of uneven application, is usually defined in terms of distribution uniformity and has a significant effect on application efficiency. It is usually determined by measuring the depth of water falling into a grid of catch cans during an irrigation event and analysing the variation of water depths in the catch cans.

Distribution uniformity (DU) is an expression that describes the evenness of water application to a crop over a specified area, usually a field, a block or an irrigation district. It applies to all irrigation methods as all irrigation systems incur some non-uniformity.

It is defined as:

$$DU = \frac{\textit{Average lowest quartile depth of water applied to crop}}{\textit{Average depth of water applied to crop}} \qquad (12)$$

The lower the value of DU, the poorer the uniformity of application and the lower the distribution efficiency.

Christiansen's (1942) uniformity coefficient (CU) is commonly used for evaluating sprinkler system uniformity. It is defined as:

$$CU = \frac{100\ [1 - (\text{sum}\ |X\text{-}x|\ )]}{\text{sum}X} \qquad (13)$$

Where: X = depth of water in individual catch cans
x = average depth of water in all catch cans

The definitions of DU and CU require that catch volumes are representative of the depth applied to equal areas, or, the catch volumes are weighted according to the area they represent.

If application depths are normally distributed and the mean depth of water applied is the same as the mean soil water deficit, Seginer (1987) showed that application efficiency can be approximated from CU as follows:

$$AE = 0.5\left(1 + \frac{CU}{100}\right) \qquad (14)$$

This definition allows only for losses due to non-uniform applications under situations where depths applied equal soil water deficits.

In trickle irrigation, distribution efficiency is a measure of the variation of emitter flows down a lateral or throughout an irrigation block.

Measurement of applied depths in trickle irrigation is more difficult, so distribution efficiency is usually specified in terms of emission uniformity (EU), which is defined as follows:

$$EU = 100\left(1 - \frac{1.27 \times COV}{\sqrt{n}}\right) \times \frac{q_{min}}{q_{ave}} \qquad (15)$$

Where: COV = coefficient of manufacturing variation for the emitters
$\sqrt{n}$ = square root of number of emitters per plant
q_{min} = minimum emitter flow in block
q_{ave} = average emitter flow in block

Application efficiency can be estimated from the distribution uniformity of the applied water. An empirical relationship has been derived to describe application efficiency based on distribution efficiency for trickle systems (Walker, 1979). However, significant design expertise is required to make this assessment, and it cannot be recommended for general use.

The value of a particular definition depends on the viewpoint of the author. Very "efficient" systems by some definitions can be very poor performers by other definitions, for example, if distribution uniformity and delivery amount are inadequate to fulfil crop need (Rogers *et al.*, 1997).

2.2 Irrigator Performance

The New Zealand Irrigation Manual (Malvern Landcare, 2001) lists the types of irrigators typically used in New Zealand.

2.2.1 New Zealand Application Efficiency Information

Verifiable information on application efficiencies measured under New Zealand conditions is becoming readily available as more research projects have been completed.

Winchmore Irrigation Research Station conducted research into irrigation efficiency during the period 1968-1977. Published results of that research are not available. However, a Technical Handbook, provided by Advisory Services Division, Volume 2, Ministry of Agriculture and Fisheries (1971), from Winchmore states:

> *"Sprinkler efficiency – it is found in practice that as a consequence of evaporation and leakage losses, effect of wind on evenness of distribution, and possible minor but cumulative inefficiencies in equipment, it is unusual to recover, in terms of increased soil moisture, more than 70% of the water entering the system. Under ideal conditions nearly 100% may be achieved, but under fairly windy conditions less than 50% of the water leaving the sprinkler may actually reach the soil."*

These findings were later shown to be of doubtful validity (P Carran, Lincoln Environmental, pers comm.), because a significant amount of water was being evaporated from the catch cans during testing.

NZS 5103:1973, Clause 4.7 states:

> *"Water application efficiency is within the range 60-90%, but see also Note 4, Table 7. For high temperature, low humidity and strong wind conditions, a figure from 60-70% should be used: For low temperature, high humidity, and light wind conditions, a figure from 80-90% should be used."*

Note 4, Table 7 in NZS 5103:1973 states:

> *"In areas where very high ET rates frequently occur, when application rates are below 6 mm per hour, consideration should be given:*
>
> *(a) To the practicality of designing the system to operate from late evening through the night until morning when, generally, hot windy conditions that would adversely affect efficiencies would not apply; or*
>
> *(b) To the use of surface irrigation. If the topography is not suitable for surface irrigation, and if it is not practical to restrict irrigation to night time operation, due allowance should be made for water application efficiencies lower than those specified in clause 4.7."*

The New Zealand Agricultural Engineering Institute (NZAEI, 1985) carried out tests under a range of travelling irrigators to determine CU and application rates under each irrigator (John *et al.*, 1985). These are presented in Table 1:

Table 1: Application efficiency vs travelling irrigator

	CU range	**Average CU**	**Application rate (mm/h)**	**AE**
Guns	19-82	70	15-20	85
Rotary boom		75	8-15	88
Linear boom	75-82	80	20-50	90
Low pressure boom		92	60-80	96
Lateral move		96	30-60	98

where:

$$CU = \frac{100\,[1 - (\text{sum}\,|X\text{-}x|\,)]}{\text{sum}X}$$

(Christiansen, 1942)

and:

$$AE = 0.5\left(1 + \frac{CU}{100}\right)$$

(Seniger, 1987)

The calculated values of AE will be higher than achieved in practice, particularly on systems with high application rates because Seginer only accounts for distribution uniformity and does not consider other factors such as drainage, evaporation and application rate.

As part of a best management practice research project for irrigation, Lincoln Environmental, over the 1997 and 1998 irrigation seasons, measured application efficiencies (based on definition 11) on a farm irrigated with a centre-pivot, a farm irrigated with border-strip and a farm irrigated with a rotary boom irrigator (McIndoe & Carran, 1998; McIndoe, 1999).

On the centre-pivot farm, application efficiency ranged from 34% to 100% in 1997, with an average of 78%. In 1998, with improved irrigation management, application efficiency rose to 96% on average.

On the border-strip farm, application efficiency was 45% on average in 1997, with a range of 31-61%. This decreased to an average of 34% in 1998, mainly due to variable flow rates and irrigation management decisions being based on the effects of water supply restrictions rather than soil and crop requirements (irrigating when water was available and keeping soil moistures as high as possible).

On the rotary boom farm, application efficiency was measured in excess of 90% when water was applied to potatoes and wheat. Soil moisture traces showed that high levels of efficiency were obtained as a result of deficit irrigating due to limited irrigation system capacity. Some loss of yield may have occurred, decreasing water use efficiency.

Two Masters projects on irrigation efficiency have been completed in Canterbury. The first was by Evans at Canterbury University (Evans, 1999) and the second by Stronge at Lincoln University (Stronge, 2001).

Using pairs of lysimeters, Evans (1999) measured application efficiencies under a rotary boom irrigator of 24-90%, with an average seasonal efficiency of 61%. On border-strip irrigation, application efficiencies of only 13% were measured. However, during the trials best-practice irrigation was not performed on these properties and the low values measured are not representative of what could be achieved. In addition, Evans states that the nature of the very stony soils at the border-strip irrigation site was such that any irrigation system located on other deeper soils would produce better efficiencies. The soils on the farms described in McIndoe & Carran (1998) and McIndoe (1999) were less stony than the soils described in Evans.

Stronge (2001) evaluated border strip irrigation for more than 175 sites throughout Canterbury, based on previously recorded field observations. The findings show an average application efficiency of 56% ranging from 30-90%. This average is higher than previously accepted levels of border-strip application efficiencies and showed that border-strip performance was close to the performance levels of some types of travelling irrigator.

An analysis of border-strip advance and recession data collected by Ministry of Works on community irrigation schemes in Canterbury showed that application efficiencies of 50-56% were able to be achieved (J Stronge, Opus International Consultants Ltd, pers comm.).

Lincoln Environmental, in research at Winchmore, measured application efficiencies under a range of sprinkler and border-strip irrigation types (Rout, *et al.*, 2002). Table 2 shows the results from this research.

Table 2: Application efficiency for different irrigator types

Irrigator type	Average Application Efficiency (%)	Range (%)
Laser-level border (Timber sill)	48	24-80
Laser-level border (Grass sill)	62	37-93
Contour Border (Timber sill)	44	27-62
Travelling Irrigator (Roto-Rainer 100)	85	76-96
Travelling Irrigator (Homersham gun)	67	62-70

Variation within application efficiency for the borders was primarily related to application depth, with lower efficiency for high depths. High application efficiency occurred when the application depth was close to pre-irrigation soil water deficit (typically in order of 50-60 mm).

The variation in efficiency illustrates the fact that application efficiency varies with every irrigation event, depending on how the water is applied and the conditions existing at the time of the irrigation event.

Lincoln Environmental, as part of an irrigation investigation completed at Ida Valley, measured application efficiencies by comparing the applied depth of water to the soil moisture retained in the top 120 mm of the soil profile (LE, 2005). Although this is not a strict definition of application efficiency as it does not consider the total root zone, it still gives good comparative values of application efficiency. The results generally showed that spray irrigation systems had higher application efficiency than border systems.

All methods were considered reasonably efficient. In the case of wild flooding and long border strips, the higher values of application efficiency were largely attributed to long return periods, meaning large soil moisture deficits at the time of irrigation. This was not necessarily an indication of effective irrigation. As part of this investigation, water use efficiency was also assessed in terms of production, which highlighted significant differences in the performance of the different irrigation methods. Wild flooding produced the lowest values of water use efficiency, while centre-pivots produced the highest.

The Ida Valley study showed that although acceptable application efficiency could be obtained by all methods, it was often at the expense of acceptable production, reinforcing the need to consider both water use and production when making irrigation efficiency assessments.

Application efficiencies were calculated from measured water use data over the 1998/2000 irrigation seasons (A Daveron, Hydro Services Ltd, pers comm.). These values (Table 3) were obtained from soil moisture measurements taken over each of the irrigation seasons.

Table 3: Application efficiency and peak 7-day water use for a range of crops

Crop	Peak 7-day water use (mm/d)	Average efficiency (%)
Peas	4.1	86
Barley	5.4	89
Clover seed	4.8	87
Ryegrass seed	5.1	81
Wheat	5.3	87
Potatoes	5.5	85
Fescue	5.0	87
Dairy pasture	5.5	71
Other crops	4.9	85
Average	5.0	78

Irrigation method also had an influence on application efficiencies. Using the Daveron data, the following was found:

Table 4: Application efficiency vs irrigation method

System type	Number of measurements	Average application efficiency (%)	Efficiency range (%)
Linear move	13	89	80-93
Centre-pivot	7	88	85-94
Side roll	8	90	86-92
Hand shift	2	89	88-91
Soft hose gun	4	89	86-93
Fixed boom (low pressure)	18	80	63-90
Fixed boom (medium pressure)	3	85	79-88
Rotary boom	18	72	48-90

These values must be used very cautiously as, in some cases, the number of measurements is small and the factors influencing the different results, such as soil type, are not known.

The higher values reflect well-managed irrigation on arable cropping farms where typically irrigation systems are controlled to apply small depths of water.

The data showed that all systems are capable of reaching application efficiencies of 90%, although on some systems such as low pressure fixed booms or rotary booms, it is difficult to consistently achieve such high values.

Eighteen irrigation system evaluations were completed covering a range of system types in Hawke's Bay, Canterbury and Blenheim in 2004/2005 (Dan Bloomer, Page Bloomer & Associates).

The evaluations focussed on application depth and uniformity (DU) from which application efficiency and irrigation adequacy was derived. The evaluations also made qualitative assessments of surface ponding, surface runoff and leakage. This shows that using application uniformity alone to determine application efficiency could result in application efficiency values higher than those achieved when considering water stored in the root zone of plants.

Table 5: Application efficiency vs irrigation method

System Type	**Field DU**	**Potential AE (%)**	**Adeq (%)**	**Ponding assessment**	**Runoff %**	**Leakage %**
Rotary boom	0.84	76	111	Medium	8	1
Rotary boom	0.81	76	95	Medium	5	1
Rotary boom	0.75	56	71	Major	20	5
Fixed boom	0.84	79	90	Major	15	1
Fixed boom	0.84	82	105	Medium	2	0
Centre-pivot	0.90	90	120	None	0	0
Centre-pivot	0.84	83	67	Medium	1	0
Centre-pivot	0.75	74	58	Minor	5	3
Centre-pivot	0.67	67	59	Medium	0	0
Multiple sprayline*	0.60	35	26	Minor	0	4
Multiple sprayline*	0.51	35	26	Minor	0	4
Multiple sprayline*	0.36	35	26	Minor	0	4
Linear move	0.88	88	93	Minor	0.5	0
Linear move	0.84	84	72	Medium	0	0
Drip/micro	0.86	86	78	None	0	0
Drip/micro	0.78	74	67	None	0	5
Drip/micro*	0.70	70	64	None	0	0
Drip/micro*	0.34	32	74	None	0	5
*	Denotes retested system after improvements made					
Field DU	The estimated overall uniformity accounting for all contributing causes					
Potential AE	Potential Application Efficiency estimated from FieldDu and losses					
Adeq	Irrigation adequacy estimated from applied depth and target depth					
Ponding	A subjective assessment of surface ponding from an irrigation event					
Runoff	A subjective assessment of overspray and runoff from the target area					
Leakage	A subjective assessment of system leakage					

Example evaluations are available at:
http://www.pagebloomer.co.nz/irrig8reports.html

Limitations of application efficiency definition

The application efficiency definitions imply that application efficiency would be high if the majority of the water applied to the soil is stored in the root zone of the crop. However, this can be achieved by applying a small amount of water to soils with high soil moisture deficits, but this would be to the detriment of optimum productivity which is the goal of irrigation. High application efficiency does not necessarily mean high water use efficiency. Conversely, sub-optimum production will almost certainly occur by applying high application depths to soils with low soil moisture deficits, both low application efficiency as well as low water use efficiency (McIndoe, 2002).

2.2.2 Application Efficiency Compared to Irrigation Efficiency

Figure 1 illustrates the difference between application efficiency (definition 8) and irrigation efficiency (definition 2) for a border-strip irrigation system (sourced from Clemmens, 2000).

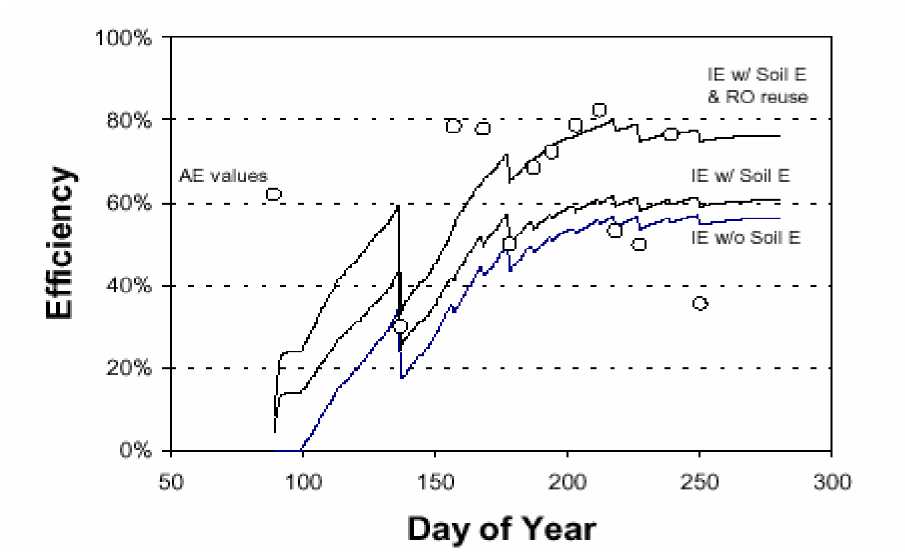

Figure 1: Calculated efficiencies for irrigation on grower's field for 1994 (Hunsaker et al., 1999)

The three curves plotted are irrigation efficiency using definition 2; without soil evaporation, with soil evaporation and with both soil evaporation and runoff reuse. Soil evaporation is usually included as a component of evapotranspiration (ET), but is irrigation-method and frequency dependent. Soil evaporation can be regarded as a non-beneficial use and when subtracted from ET, gives basal crop transpiration, which is beneficial. Treating soil evaporation as non-beneficial lowers both irrigation efficiency and beneficial use if basal transpiration alone is regarded as beneficial.

Application efficiency (using definition 8) is shown as single events (the circles). Often, there is a large difference between application efficiency and irrigation efficiency. However, the irrigation efficiency and aggregate application efficiency should be the same at the end of the year, if all soil evaporation and runoff is considered beneficial and leaching is not beneficial.

Irrigation efficiency starts low and increases over the season because water lost from the system (non-beneficial use) is counted at the time of application, while beneficial consumption is counted when water is used via crop ET. It shows that irrigation efficiency does not recover quickly from poor applications early in the irrigation season.

If low application efficiency results in non-beneficial use such as leaching, it will result in low irrigation efficiency. This illustrates the importance of maximising application efficiency throughout the season to obtain maximum irrigation efficiency where beneficial use is restricted to the field level.

2.2.3 Overseas Application Efficiency Information

McIndoe (2002) found that several US universities have published application efficiencies for a range of irrigation system types. Examples from California State University (Solomon, 1988) and Kansas State University (Rogers *et al.,* 1997) are given in Table 6. These values are intended for general system type comparisons and should not be used for specific systems.

Table 6: Application efficiencies of irrigation systems

System type	Solomon, 1988	Rogers *et al.*, 1997
Surface irrigation		
Border	70-85	60-90
Sprinkler irrigation		
Hand move or portable	65-75	65-80
Travelling gun	60-70	60-70
Centre-pivot & linear move	75-90	75-90
Solid set or permanent	70-80	70-85
Trickle irrigation		
With point source emitters	75-90	75-95
With line source products	70-85	70-95

Data from Arizona State University (Clemmens, 2000) has also been published for attainable application efficiencies for a range of system types, as shown in Figure 2.

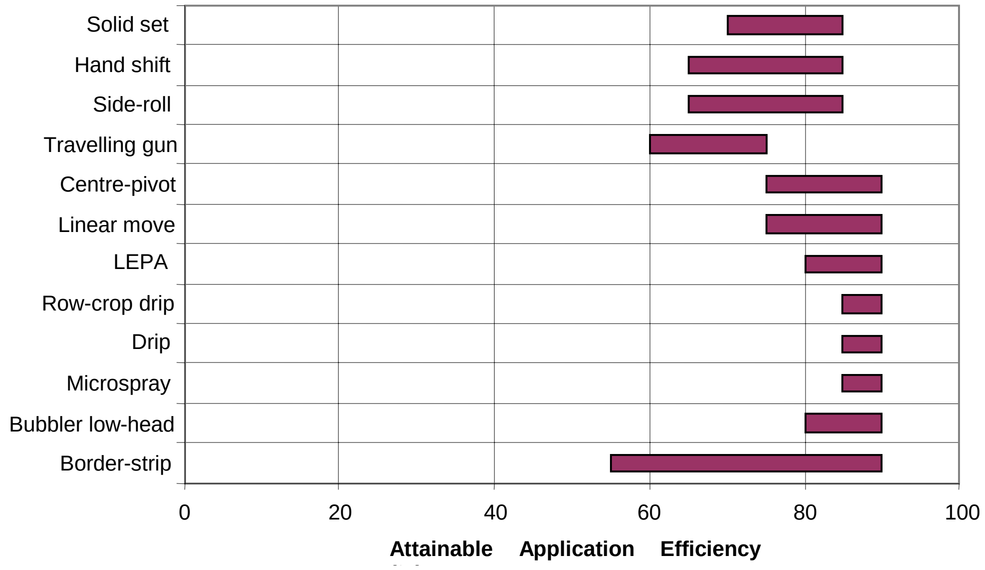

Figure 2: Attainable application efficiencies for different system types

2.3 Key Factors Affecting Efficiency

The following summary of information has been sourced from McIndoe (2002).

The key factors that influence irrigation efficiency are how well the system is designed and how well the system is managed. Irrigation system design is the principal reason for lower than expected levels of efficiency (LE, 2000).

The design of the system is crucial for the future operation and management of the irrigation system and the potential for efficient irrigation. With poor design, attainable irrigation efficiency will be low, regardless of the standard of system management. With good design, high efficiency will be attainable but whether it is achieved or not still depends on how well the system is managed.

Table 7 shows the expected losses on components of typical spray irrigation systems in New Zealand. This helps to identify where the focus should be when looking at improving application efficiency.

Table 7: Expected water losses on spray irrigation systems (collated by McIndoe)

Source of loss	Range	Typical
Losses from open races	0-30%	10%
Leaking pipes	0-10%	<1%
Evaporation in the air	0-10%	<3%
Blown away by wind	0-20%	<5%
Watering non-target areas	0-5%	<2%
Interception by plants	0-3%	<2%
Surface runoff	0-10%	<5%
Uneven application (non-uniform distribution)	5-30%	15%
Excessive application depth	0-50%	10%

Evaporation loss in the air tends to be small, ranging between 0-3% for typical irrigation situations (Schneider & Howell, 1993). Interception (canopy evaporation and foliage evaporation) can range from 0-12% (Schneider & Howell, 1993), but some of the water "lost" to wind drift and evaporation from sprinkler sprays is not actually lost, since it substitutes for crop transpiration (Solomon, 1988). Net losses in this case are normally 1-3%, but could be as high as 15-20% under extreme adverse conditions of very low humidity, high temperatures and strong winds as occurs in desert climates. These conditions rarely occur in New Zealand.

Well maintained sprinkler systems should have leak and drainage losses below 1%, but poorly managed systems have shown losses of up to 10% (Solomon, 1988). Fortunately, these losses are generally visible and can be prevented. It should also be noted that leaks in piped systems often occur underground months or years after the system was installed and are more difficult to detect. However, these losses tend to be very small.

Table 7 shows that the main losses within an irrigation system are due to uneven/excessive application depths and are therefore the areas with the greatest potential for improvements in efficiency. Excessive application is largely due to inflexible design or is a management issue. Uneven application usually results from poor distribution uniformity (wind or by substandard sprinkler distribution patterns), or by excessive application rates causing surface redistribution.

Good design can account for 5-40% of efficiency improvements by correctly matching applications of water to soil water holding capacity, soil infiltration rates and applying water uniformly. Irrigation management can improve efficiency by 5-20% by applying the right depth of water in the right place at the right time.

2.3.1 Other Relevant Research

Ministry for the Environment is funding research looking at groundwater contamination through leaching of fertilisers and chemicals under irrigation. They are also funding research on water allocation issues and how they relate to irrigation efficiency.

A report is being prepared for Dairy Insight by New Zealand Institute for Crop and Food Limited, which is a review of literature on the principles of water use efficiency and pasture plant response to water application.

Further Sustainable Farming Fund funded work is also being carried out in North Otago (SFF grant 04/004) which is expected to provide assessments of application efficiency and guidelines for improving irrigation design on rolling hill country.

2.4 Guidelines for Best Management and Design Practices

Good design incorporated with good management of irrigation systems is critical to achieving high irrigation efficiency. Without good design, irrigation efficiency improvements that can be made with management are limited and are in fact hampered (Bright, Carran and McIndoe, 2000).

Also critical to achieving high efficiency is having access to a reliable water supply, so that water can be used when it is needed rather than when it is available. Although having access to a reliable water supply is usually an economic or engineering issue, its importance is often understated, and further effort needs to be put into improving the reliability of water supply systems and providing water on demand if efficient irrigation is to be achieved on a broader scale.

Malvern Landcare Group (backed by several organizations) initiated a project to collate recent research and current knowledge about irrigation design and management (Malvern Landcare, 2001). This information is presented in the form of an irrigation handbook, which has been made available to farmers and others with an interest in irrigation. Its primary purpose is to help farmers increase the profitability of irrigated agriculture, reduce environmental impacts and demonstrate the degree of sustainability of irrigated agriculture, but it also provides a valuable reference source for anyone involved in irrigation or irrigation related activities.

The Farmers Irrigation Management Group of South Canterbury initiated a project to develop an irrigation guide (McIndoe *et al.,* 2002) to assist farmers who are considering irrigation development. This guide provides information on parameters for irrigation design, system design and operation limitations, and practical solutions for improving efficiency through better design. The guideline was developed in response to a need to provide basic information on irrigation development to farmers contemplating irrigating from the Opuha Irrigation Scheme.

2.4.1 Guidelines for Best Management Practices

A sustainable management fund project (Bright & Robb, 1996) highlighted the potential impacts that irrigated agriculture may have on groundwater quality. More importantly, the study identified that, through improved irrigation management practices, these impacts could be significantly reduced. Following this, MAF initiated several projects to provide information to farmers on how to improve the level of irrigation efficiency and how to attain sustainable irrigation.

A survey of farmers was conducted to obtain information about their approaches to and perceptions on irrigation management (LE, 1997a). This provided a good summary of what irrigation efficiency means to farmers.

The survey found that farmers focus more on the effectiveness of irrigation (production versus water use) rather than application efficiency. For example, they may apply more water to overcome uneven applications to ensure optimum production even though more water is required to do that. It implies that increased production or risk minimisation is of greater importance than the marginal cost of applying the water (energy and labour). The rationale is that it is better to irrigate and minimise risk than to not irrigate and risk production losses. Part of the rationale for taking this approach is that the marginal cost of applying the additional water is relatively low, compared to the potential losses from not irrigating, as the only additional costs are the direct costs associated with applying the extra water.

Many farmers knew little about how evenly water was being applied. Soil moisture and water use are often not measured, which makes it difficult to calculate efficiency. Effectiveness is therefore assessed through measurements of production and profit.

The study found that many systems do not have the flexibility to be managed to achieve high efficiency and that many farmers would like to improve irrigation systems but are constrained by lack of resources, time, and incentives to obtain and apply the best available information.

Indicators of irrigation performance have been developed as part of the MAF initiative (LE, 1997) to enable farmers to make better informed irrigation management decisions. Farmers clearly indicated that the overall primary goal for farmers was to maximise net profit in the long term. Given that goal, a list of indicators for sustainability of irrigation was developed, which included economic, production, energy, labour, water, environmental and soil factors.

Following their development, the indicators were field-tested to determine their suitability for general use (Wells *et al.,* 1998). The field-testing showed that it was reasonably easy to evaluate and interpret the economic/technical indicators. However, the environmental indicators were not as easy to evaluate because accurate water measurement and soil moisture data, which was critical for determining indicators, was often not available. What the field-testing did show was that, given appropriate monitoring, the use of indicators could provide a very worthwhile approach to improving and sustaining irrigated agricultural systems.

A further report “Best Management Guidelines for Sustainable Irrigated Agriculture” provides advice on how to use these indicators to achieve sustainable irrigation through improving design and management of irrigation systems (LE, 1997b). The guidelines also have practical advice on planning new systems and the issues to consider. These guidelines were also field-tested. It was concluded that by following the best management guidelines (McIndoe & Carran, 1998, and McIndoe, 1999) and adopting changes recommended from design audits, irrigation efficiency could be improved without compromising overall production, and in fact improve profits while minimizing environmental effects.

A project "Benchmark Data on Sustainable Irrigation Indicators" (Greer, 1999) was conducted on 30 farms covering a range of irrigation systems and farm types. The benchmark indicators could be used by other farmers who are interested in using the indicators to compare their own values with the benchmarks.

2.4.2 Guidelines for Design of Irrigation Systems for Efficient Irrigation

It is important to design irrigation systems with enough flexibility, so irrigation managers are able to irrigate in a way that is both effective and efficient. Given that irrigation system design had been determined to be the principal reason for lower than expected levels of efficiency, MAF initiated a project to define the performance measures that need to be considered when designing an irrigation system for effective and efficient irrigation (Bright, Carran and McIndoe, 2000).

The critical factors identified specific to irrigation design were timing of applications, application depth, uniformity of application and water supply reliability characteristics. For an irrigation system to create the potential for high performance, it must be designed to irrigate uniformly, with the ability to apply the right depth at the right time (Bright *et al.*, 2000).

A case study, initiated by MAF, was completed to demonstrate the financial benefits of making design improvements to an irrigation system (Borrie & McIndoe, 1998). An audit was completed on an existing irrigation system from which specific recommendations were made for improvements. This study showed that there were financial benefits to making these design improvements through reductions in annual operational costs alone.

Because there are no performance standards or codes of practice for irrigation system design in New Zealand, INZ, as part of its charter to promote economically and environmentally sustainable irrigation, has taken a proactive step and initiated the development of irrigation system design performance standards and a code of practice. Development of the code has been financially supported by MAF Sustainable Farming Fund (Grant 02-079).

INZ's aim is to improve the efficiency and sustainability of use of water, energy, labour and capital in irrigation systems in New Zealand. To meet this aim with respect to irrigation design, four key developments had to be completed as follows:

1. Key performance indicators (KPIs) for irrigation systems and minimum acceptable standards for the KPIs.
2. An irrigation design code of practice, that, with the KPIs, describes the minimum acceptable design practices for the irrigation industry.
3. An industry recognised designer certification programme.
4. NZQA recognised unit standards for the training of irrigation designers to the standard required to achieve the standing of Certified Irrigation Designer.

To date, the key performance indicators have been developed and a code of practice written. The designer certification programme and NZQA recognised unit standards are currently under development.

2.4.3 Design Evaluations

Projects for evaluating irrigation systems have been or are being carried out in most of the irrigated regions in New Zealand.

Landwise Hawke's Bay initiated a project to audit a range of irrigation systems to establish benchmark performance levels for the standard of irrigation design in the district (McIndoe, 2000). A range of performance indicators were assessed as follows:

- Application efficiency
- System capacity
- Return interval
- Hydraulic efficiency
- Energy use efficiency

The key recommendations that arose out of the evaluations were to:

- Understand irrigation requirements and soil plant needs. Understanding soil properties is critical for design.
- Design a farm around the irrigation system rather than fitting the irrigation system around a farm.
- Where practicable, use irrigation systems that apply water reasonably uniformly with the lowest application rates practical.
- Design systems to a best practice standard
- Keep appropriate records of system installation
- Improve energy use by better selection of pumps.

Irrigation investigations were undertaken in Ida Valley (LE, 2005) where the purpose of the investigations were to identify practical and affordable ways to produce more with the water available and recommend ways to improve efficiency. The key recommendations included:

- Improving irrigation management and planning including scheduling irrigation based on soil moisture monitoring
- Concentrating on irrigating a small area well, rather than spreading the water too thinly
- Targeting the best soils on each property for irrigation
- Using higher flows for shorter timeframes when flood irrigating
- Improving maintenance, e.g. re-grading of borders and sill maintenance

Design evaluations were undertaken on ten farms within the Waihou catchment to assess their efficiency levels (Aqualinc, 2005). The results indicated that current systems and management are relatively efficient although some of the high application efficiency was related to under-capacity of systems relative to the area irrigated.

In parallel to the Irrigation Design Code of Practice, a Code of Practice for On-Farm Irrigation Evaluation (Bloomer, 2005) (SFF grant 02/051) has been developed to provide guidelines for people undertaking evaluations of irrigation systems in the field. It makes specific recommendations for planning and conducting evaluations and reporting on the performance of irrigation systems and their management.

The Evaluation Code has been developed with reference to the New Zealand Irrigation Design Code of Practice, and international practices and standards. The main aim of the evaluation code is to encourage adoption of standardised evaluation practices that are cost-effective, recommendation driven and encourage more efficient use of irrigation resources. Its focus is on water application efficiency, but other key performance indicators are addressed. Evaluations of irrigations systems as described in the Evaluation Code have been trialled on several farms over 2004/05 and the data presented in Table 5 has been obtained from these trials.

2.5 Monitoring and Measuring

Measuring water use and soil moisture is crucial for calculating irrigation efficiency. Until recently, very little water use measurement and soil moisture monitoring has occurred. Progressively more irrigators are implementing water use measurement and soil moisture monitoring to improve irrigation management, but there are still many farmers not routinely measuring irrigation water use or soil moisture.

2.5.1 Water Use

To assess, or to calculate, irrigation efficiency and the related indicators of efficient irrigation, either the volumetric use of water (usually cubic metres per year) or the depth of water applied in the field needs to be known or measured.

Today, water meters placed at the water supply point are often required to satisfy conditions of consents to take and use water. This has not always been the case, and some areas such as Canterbury have only recently implemented water metering policies. Water meters at the supply point usually provide useful information about annual volumes of water taken and may meet consent compliance requirements but don't always provide the information required to determine application depths on a particular field unless the system consists of a single source and single irrigator.

Traditionally, application depth has been estimated by using data from irrigation system suppliers or sprinkler manufacturers (McIndoe *et al.*, 1998), but this in practice is compromised by:

- Pressure fluctuations in water supply lines.
- Poor data relating to travel/rotation speed of travelling irrigators and their running time.
- Poor data on the "as installed" hydraulic characteristics of irrigation systems.

MAF initiated a project to develop an irrigation water use meter that could be easily installed in the field (rather than at the water supply point), was robust and would give reliable data on different types of pressurised systems (McIndoe *et al.*, 1998). Although a prototype was developed and the concept of measuring water use in the field shown to be practical and functional, the meter has not yet been commercialised.

2.5.2 Soil moisture monitoring

Although knowing the amount of water stored in the root zone of a crop is a key requirement for determining application efficiency, it is impractical to accurately measure water stored in the root zone of a crop on the field scale. Soil moisture measurement is commonly used to provide values at the specific measurement locations. Given the wide variation in soil water holding capacities, soil depths, crop root depths, crop water use and application depths, a true measure of water stored in the crop root zone is difficult to obtain.

Despite its limitations, soil moisture measurement is one of the best methods of providing information to farmers to enable them to manage irrigation applications to achieve both high application efficiency (providing the irrigation system has that capability) and high water use efficiency (McIndoe, 2002). Effective soil moisture measurement is used as a tool to avoid under-irrigating and over-irrigating, reducing the risk of losses in crop production.

Soil moisture measurement technology has improved significantly over recent years, with a wide range of devices now available. The NZ Irrigation Manual provides a practical guide for soil moisture monitoring and lists the currently available methods (Malvern Landcare, 2001).

Further to the available options is "Irrinet", which is an internet-based soil moisture information site that has been developed and set up in a number of irrigation regions. The Irrinet system currently provides soil moisture monitoring and from that daily crop water use data on a number of sites in North Otago, Central Otago (Ida Valley), Te Pirita and Lincoln.

The purpose of the Irrinet system is to allow farmers (even if they do not have soil moisture monitoring on their property) to use the water use data measured on farms with similar characteristics (e.g. within the same region with similar irrigation system setup) to help them make decisions on when to irrigate and how much water to apply.

3 INTERACTION OF OTHER FACTORS AS THEY AFFECT IRRIGATION

3.1 Efficiency in Economic Terms

An irrigator's main objective is to reliably maximise or enhance production and therefore profits. Reducing capital and operational costs and irrigating efficiently will help maximise returns and achieve this goal.

The cost of water in the past has been considered reasonably low, providing little value/incentive to improve efficiency on the basis of the cost of water alone. As stated above, risk minimization was of higher priority than reducing water use.

More recently, there has been a shift to the installation of more efficient systems and improvements to existing systems. This is partly attributable to increasing energy costs, particularly with many spray irrigation systems and implies that costs are now starting to drive the change towards more efficient irrigation.

Another driver of more efficient systems is the ability to produce more output with greater reliability in water short areas. Higher efficiencies are also enabling water to be applied over larger areas, particularly within irrigation schemes.

There is also greater recognition of the fact that it is easier and cheaper in the long run to initially install an efficient irrigation system than it is to upgrade an irrigation system to improve its efficiency at a later date. Although the initial capital cost of irrigation systems is a key deciding factor in the choice of irrigation systems, there is now greater awareness of the importance of on-going operating costs, particularly pumping costs, maintenance costs and labour costs, than was the case in the past. Low initial capital cost is often not the best option in the long term as it may mean high annual operating costs, labour costs or high maintenance costs. More farmers now realise that initial higher capital investment will be returned through improved management and performance of the system. Part of the initial investment is now often put to monitoring equipment.

Despite the obvious benefits of more efficient systems, designing a system that is 100% efficient, although technically possible, may not be financially viable and it is important to strike a balance between application efficiency and other interacting factors such as capital cost, operational cost and labour.

Some irrigators may see little incentive for improving irrigation efficiency when they have an existing scheme which is operating ‘adequately’. Studies have shown that it is financially beneficial for farmers to upgrade the irrigation system (e.g. Borrie & McIndoe, 1998). Although this may require capital expenditure, the operational cost reductions that can be made are likely to make this option viable over the long term. Design evaluations have also shown that, through careful management and good design, costs can be reduced, which improves the economics of the system. Even small changes in system design and management can make a large difference to efficiency and cost improvements.

3.2 Irrigation Efficiency and Energy

Upgrading an irrigation system and improving irrigation management to increase irrigation efficiency should ultimately reduce the use of energy. This is achieved through initiatives such as the use of more efficient pumps, lower operating pressures and reduced operating hours.

A typical example of inefficient energy use arises when a medium pressure irrigator has been used to replace an existing high pressure gun. Often, instead of replacing the oversised pump (which requires capital investment), a farmer will decide to use a pressure reducing valve or throttle the main valve to burn off the excess pressure, wasting energy. Is likely that long term it would be better to install a pump that matches the required duty.

Several projects have been completed that have investigated the potential savings in energy that could be obtained through more efficient irrigation design or management.

McIndoe and Robb (2000) and McIndoe (2001), in projects investigating the potential for energy savings in irrigated agriculture, found that significant savings in energy use could be made by improving the design and management of irrigation systems.

A project carried out for Landwise Hawke's Bay identified that significant reductions in energy use could be achieved by better matching pumps to required system duties or through improving the hydraulics of the system (McIndoe, 2000).

A detailed review of issues associated with irrigation energy use was made by McChesney *et al.*, 2004. The review found that irrigation energy requirements are primarily associated with pumping. A secondary use (and very minor) is to run electric motors to propel electric centre-pivots and lateral move irrigators.

In a project involving evaluating total energy indicators of agricultural sustainability using a dairy farming case study (Wells, 2001), it was found that average energy intensities on dairy farms in New Zealand were similar in all regions except Canterbury where they were significantly higher due to the number of farms with pumped irrigation.

McChesney *et al.* (2004) state that power requirements (kilowatts) depend primarily on the pressure and flow rate of pumping systems, and various energy conversion efficiency factors. Energy use (kilowatt-hours) depends on power requirements, how long the system is operated (operating hours), and various water use efficiency factors. The key factors are described in Table 8, indicating the typical overall effect each factor has on energy use.

Table 8: Effect of irrigation factors on energy requirements (from McChesney et al., 2004)

	Components	**Effect on energy**
Pump pressure	Depth from which water is being lifted from a well (or other source)	Strong
	Elevation to which water is being pumped	Generally small but can be strong
	Energy absorbed in the drive system of the irrigator (if water-driven)	Generally small
	Pressure at which the water is released from the irrigation outlets	Moderate- strong
Flow rate/ volume of water pumped (flow rate times hours pumped)	Water demand of the crop (crop type, climate, soil characteristics)	Moderate/strong
	Area irrigated	Strong
Efficiency factors (energy and water)	Motor and pump efficiency	Small-moderate
	Losses in the pipe network, reticulation and hydraulic control system	Generally small
	Efficiency of the well and well screen	Generally small
	Efficiency with which water is delivered to the soil by the irrigation device	Moderate
	Efficiency with which the farmer manages the timing and quantity of water applications	Moderate-strong, particularly in high rainfall years

It is important to carefully assess the potential changes within an irrigation system when upgrading because any changes can change the operation of system dramatically. There are other design issues that affect energy usage including system type, layout and mainline size.

Typically many people view flood irrigation such as border strip irrigation as being inefficient compared to spray irrigation because of the belief that border-strip irrigation tends to have lower application efficiency than spray irrigation. Although surface irrigation can be designed to be as efficient as most spray irrigation systems in terms of application efficiency, on average it is not. However, border irrigation operates in most cases under gravity supply and has no energy (pumping) requirements. The efficiency of border-strip irrigation when considering both application efficiency and energy efficiency may compare favourably to spray irrigation systems, which in most cases require pumping.

3.3 Irrigation Efficiency and Labour

The cost, availability and reliability of labour for irrigation has become significant. Although the time required to operate irrigation systems overall has probably reduced because of the wider use of labour-efficient irrigation methods such as centre-pivots, labour is still limiting the ability to manage many systems efficiently. In particular, to obtain high efficiency, many travelling irrigator systems should ideally be shifted twice daily. However, because of the labour requirement, irrigation system operators often choose to accept a lower level of application efficiency to obtain what they regard as a better outcome in terms of overall irrigation efficiency.

Very little formal investigation into the labour requirements of operating irrigation systems has been carried out. Some indication of labour requirements for different types of irrigation systems, expressed in general terms, is given in the NZ Irrigation Manual (Malvern Landcare (2001). Further work needs to be carried out to determine the relationship between labour requirements, capital expenditure (replacing labour with capital) and the impact on irrigation application efficiency and production.

3.3.1 Well Performance

One of the key potential areas for reducing energy use identified in McIndoe and Robb (2000) and McIndoe (2001) was well efficiency, because of its impact on the depth from which water needs to be lifted from a well and the fact that so many irrigation systems draw water from wells.

Drawdown in a well, which is the depth that water levels fall from their static water levels when pumped, is caused primarily by pressure loss in the aquifer and pressure loss in the well itself. The drawdown caused by the aquifer is related to aquifer properties (in particular, transmissivity) and the drawdown caused by the well is related to the construction and development of the well (McIndoe, 2002).

Potentially, through improved well construction and development, well losses could be reduced thereby reducing the total drawdown, pump duty requirements and energy costs. At this stage the relationship between well efficiency and well construction is poorly understood and requires further research (McIndoe *et al.*, 2001).

3.4 Efficiency in Terms of the Environment

Irrigating efficiently can provide benefits to the environment including:

- Less stress on water resources
- Lower losses of water and nutrients to groundwater and surface water resources
- Availability of water to other users
- Better public perception of irrigation.

For irrigation to be sustainable in the future it is important that potential environmental impacts are minimised. Therefore there is a need to irrigate efficiently to improve economic and environmental performance in a complimentary way.

Not all irrigation systems have high application efficiency. If it can be shown that there is no significant disadvantage to the environment or to other users in having lower application efficiency or if modifying a system may make it uneconomic or unworkable, lower application efficiency may be desirable.

3.4.1 Water Quantity Issues

When considering the efficiency of an irrigation system, it is important to define appropriate hydraulic boundaries as this can dramatically affect the perception of whether the system is efficient or inefficient. Often, low application efficiency or distribution system efficiency does not mean that the water is lost to additional abstractive use or to the environment. In many cases it is simply being moved from one location to another and be available for use by others. Therefore it is important to consider not only farm scale rather but field-scale hydrological boundaries, otherwise beneficial/non-beneficial use issues maybe overlooked.

Farmers need to consider efficiency at the farm scale where application efficiency is important. Application efficiency however only considers the efficiency of a single event at the paddock scale. At the paddock scale, the system may be deemed to be inefficient, but when considered in a wider hydrological setting, the overall use efficiency may still be high. Under low application efficiency, excess water applied may drain through the soil profile recharging underlying aquifers and due to the inter-connection between aquifers, this water may be beneficially re-used elsewhere in the system. It would be non-beneficial if runoff, deep drainage and evaporation from non-crop areas such as canals or roads and leakage from pipes or canals are not re-used. This means that water managers need to give greater emphasis to regional scale impacts for the purposes of water resource management and consider paddock-scale application efficiency within the context of the wider hydrological boundaries of the region.

As an example of re-use occurring under farm-scale irrigation, some border strip irrigation is supplied by the Opihi River to the top of the Levels Plains Irrigation scheme and spray irrigation supplied by groundwater nearer the bottom. Border-strip irrigation is generally considered inefficient because its water application efficiency is low. But if you consider the entire scheme, the groundwater fed area depends on the recharge from the surface irrigation area to operate. More recently with the reduction in area of border-strip irrigation, the groundwater supply for the lower reaches has become less reliable and there are now problems operating some of the groundwater supplies.

Mayfield-Hinds Irrigation Scheme is also a good example of where deep drainage from border-strip irrigation is utilised through higher groundwater tables in the lower areas of the same district and although the application efficiency of the border-strip scheme is low, the irrigation efficiency for the district may be high.

The Lower Waitaki Irrigation scheme has multiple uses including satisfying crop water demand, keeping the scheme physically operational, supplying stock water and industry. The races have continuous flows, which has meant that enhancement has occurred with environmental habitats now established. This provides direct and indirect environmental enhancement. Most irrigation efficiency definitions do not take account of multiple uses and the economic and environmental benefits of multiple uses of having lower application efficiencies.

Therefore low application efficiency (at the paddock scale) does not necessarily mean low overall efficiency when considering the whole scheme (district scale) as the water may be able to reused elsewhere in the system.

3.4.2 Beneficial Uses

In defining beneficial use the boundary area is critical (Burt & Styles, 1994). Beneficial uses of irrigation include replacing crop ET (the primary reason for irrigating), crop cooling, frost protection, crop germination, leaching (limited requirement in New Zealand) and pest control. Although frost protection results in the highest peak use in terms of litres per second per hectare, meeting crop ET requires the highest volumetric use over an irrigation season.

3.4.3 Water Quality Issues

Nutrient leaching is likely to occur under poorly designed and installed systems with low application efficiency. On-farm monitoring (water use and soil moisture) to enable good irrigation management improves the likelihood of efficient irrigation, minimising these adverse effects. Where drainage water under irrigation can be reused (either by other abstractive users or by the environment), maintaining water quality may be a more important reason for striving for high application efficiency than minimising water use from a quantity perspective.

3.5 Other Important Issues

3.5.1 Water Supply Reliability

For irrigation efficiency to be maximised, water supplies need to be reliable and water needs to be available on demand.

The survey of farmers (LE, 1997a) identified that lack of water supply reliability was a constraint on the efficient operation of irrigation systems. Water supply reliability has a significant effect on the decisions farmers make with respect to management of their irrigation system. The most efficient irrigation systems are those that supply water on demand without the uncertainty of restrictions. Unreliable water supplies result in lower irrigation efficiency because of the behaviour that unreliable water supplies bring about.

On systems subject to water supply restrictions, farmers often irrigate as much as possible (even if not needed) before restrictions are likely to occur, so that, if restrictions do occur, soil moisture levels are as high as possible reducing the risk of low soil moisture levels. This approach applies whether the restrictions are caused by environmental restrictions such as minimum flows or groundwater levels, or infrastructural restrictions such as water supply rosters.

As an example of unreliable water supplies resulting in low application efficiency, Rakaia River supplied irrigators almost always irrigate at the end of the month in spring and summer regardless of soil moisture conditions, because minimum flows on the Rakaia River increase over that period. Because restrictions are more likely to occur in the first part of the following month, farmers irrigate at the end of the previous month to minimise the risk of production losses.

In the case of rostered systems (usually open-race systems), farmers tend to take and use the water when it is available, knowing that it will be a fixed period (for example 14 days or 21 days) before they will have access to water again. They irrigate whenever water is available to keep soil moistures as high as possible because if they don't, production losses could occur in the intervening period between the last and next irrigation event.

Unreliable water supplies do not only impact on the efficiency of on-farm irrigation systems. They also impact on the efficiency of irrigation schemes off-farm. Most existing open-race irrigation schemes were designed based to operate at full flow to achieve maximum distribution efficiency, and in most cases reducing flows reduces the distribution efficiency of the scheme. For example, evidence presented to the Rangitata Conservation Order hearing showed a 20% cut in flow at the Rangitata Diversion Race intake resulted in a 35-40% reduction in water available to plants.

3.5.2 Optimising use of Rainfall

The most inexpensive form of water application is rainfall, so it is logical to make as much use of rainfall as possible to meet crop needs. By calculating application efficiency for rainfall events, it is possible to determine how well rainfall has been used. It is possible to have high irrigation application efficiency but low rainfall application efficiency. This was observed in the best management practice project for irrigation on the centre-pivot farm (McIndoe & Carran, 1998; McIndoe, 1999).

The closer that soil moisture is maintained to field capacity the more likely rainfall will be lost to drainage (LE, 1997b), because rain is falling onto wet ground and is able to drain through the soil profile. Ideally, the most efficient use of rainfall occurs when irrigation is managed so that soil moisture is retained at just above the crop stress point, leaving significant soil moisture storage for rainfall. This is achieved by applying small depths of water frequently and is only realistically possible using irrigation systems such as centre-pivots or solid-set automatically controlled systems.

The benefit of this approach was illustrated in a field day describing a Sustainable Farming Fund project (SFF00/295) that aimed to improve water use on dairy farms by providing the decision-makers (farmers) with the right tools (Street, pers comm. 2003), where a very high level of irrigation application efficiency and rainfall application efficiency was achieved.

There are two constraints that have to be considered when operating irrigation systems to maximise the use of rainfall. The first is that many irrigation systems are not designed to the level of capability needed to maintain soil moistures within a narrow band around the stress point. It is more realistic to operate over a wider soil moisture band, typically from just above the stress point to just under field capacity. The second is that operating in such a tight band exposes the production system to greater risk to unplanned stoppages or water supply restrictions. To operate at that level requires a reliable water supply, reliable irrigation system and reliable monitoring systems.

To improve overall efficiency there is a need to optimise the use of rainfall efficiency. This increases risk in the system and a very reliable water supply and irrigation system is required to do this. But, ultimately optimising the use of rainfall improves efficiency and reduces irrigation costs.

4 GAPS IN KNOWLEDGE

The irrigation efficiency survey (LE, 1997a) and the review of available information showed that there is a lot of information available on the subject of irrigation efficiency and that at least some people have a reasonable understanding of the subject.

A significant amount of irrigation related research was completed in the 1970's and early 1980's but very little was then done until the mid 1990's, when MAF took the initiative to progress things further.

Since the mid 1990's, a lot of useful information on irrigation and irrigation efficiency in New Zealand has been completed. A significant amount of knowledge about current irrigation practices and the measures required to improve irrigation efficiency exists, but has not been well-transferred to the general public or practitioners in the field. The biggest gap therefore, is communicating the knowledge to stakeholders.

There appears to be further opportunity to improve efficient use of water through measuring actual water use and measuring soil moisture. Although the benefits of measuring application depth and soil moisture are well recognised, some of the reasons farmers are not measuring these items have been identified. Initiatives such as the Ida Valley and North Otago projects are designed to help to communicate these benefits to farmers, and some progress has been made. The Irrinet system is also aimed at this outcome.

Better understanding needs to be gained about the relationship between water application, energy use, labour and capital expenditure when quantifying irrigation efficiency in the wider context. Although quite a lot of information is available on the energy aspects of difference systems and ways to improve energy efficiency have been identified, very little information on labour requirements for irrigation and issues associated with labour is available.

When purchasing irrigation schemes, farmers appear to give greatest weight to up-front capital costs, and information on ongoing operating and maintenance costs is rarely available. Further information needs to be obtained in these areas and communicated to farmers.

Although application efficiency as it relates to application uniformity is reasonably well understood, very little information is available on the uniformity of water application measured at the crop root zone of the soil. The impact of irrigation application rates exceeding soil infiltration rates causing surface redistribution and potential runoff and how that impacts on crop production is not well understood.

Some initial work on this was done by NZ Agricultural Engineering Institute in 1985 (John *et al.*, 1985) and further work is now being carried out by Bloomer in Sustainable Farming Fund project 05/051, which is aimed at quantifying losses resulting from surface ponding during irrigation. However, it is a very difficult thing to do and if the benefits on crop production of substantially reducing the surface water redistribution and ponding are to be quantified, further research will probably be required.

Following on from this issue, the wider benefits of using one particular irrigation method versus another have not been well quantified. Even a simple commonly-asked question such as what type of system grows the most grass cannot be easily answered or quantified. Most of the available information is anecdotal, although the Ida Valley research (LE, 2005) and Waihou research (Aqualinc, 2004) did provide some initial data. More information will become available after current projects such as those being carried out in North Otago have been completed.

There are gaps in our knowledge of well performance and well efficiency and in particular how to construct wells to maximise well efficiency. Improving well efficiency will improve the economics of irrigation from wells and could substantially reduce energy requirements for pumping from deep wells.

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