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Environmental
Monitoring Group

Efficient and Reasonable Use of Water for Irrigation:

Environment Canterbury
Your regional council

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Report No. U01/69

May 2002

Prepared for

Environment Canterbury

by

Ian McIndoe

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Natural Resources Regional Plan

Efficient Irrigation

PREPARED FOR ENVIRONMENT CANTERBURY

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EXECUTIVE SUMMARY

Environment Canterbury (ECan) is currently preparing a Natural Resources Regional Plan (NRRP) to manage the natural and physical resources of the Canterbury region. The NRRP sets out detailed objectives and policies for setting and managing water allocation. A major part of the available water resource is allocated for irrigation. How efficiently that water is used impacts on how water is allocated and what potential adverse environmental effects could arise.

The purpose of this report is to define irrigation efficiency, recommend a reasonable and desirable level of irrigation application efficiency for use in allocating water for irrigation, and to review conditions of water use. The information will be used to develop and promote policy in the NRRP, be incorporated in a reasonable use test for setting water permits, and assist in the fair allocation of water resources with the least environmental effect.

Fourteen definitions of efficiency have been described and evaluated.

For allocation of water for irrigation and for inclusion into a reasonable use test, the following definitions are recommended:

$$\text{Irrigation System Efficiency} = \frac{\text{Water applied that is stored in crop root zone}}{\text{Total amount of water delivered to the farm}}$$

$$\text{Application Efficiency} = \frac{\text{Water applied that is stored in crop root zone}}{\text{Average depth of water applied to crop}}$$

For allocation of water and for determining reasonable use, an application efficiency of 80% is recommended for all spray and trickle systems.

For surface irrigation systems in water-short areas where losses to drainage do not have a beneficial use, an application efficiency of 80% is also recommended.

For border-strip systems where losses to drainage have a quantifiable beneficial use, where there are no adverse effects and where water supply is not limited, application efficiencies of 50% are recommended.

If the application of water has other benefits in addition to replacing soil moisture deficits, such as for germination, cooling, frost protection, leaching and pest control, a broader definition is recommended. The following definition is preferred:

$$\text{Irrigation Application Efficiency} = \frac{\text{Average depth of irrigation water contributing to target}}{\text{Average depth of irrigation water applied}}$$

Because targets other than replacing soil moisture deficits are included, an application efficiency of 80% is recommended for all irrigation systems.

The current reasonable use test is inadequate as it is based on 'average' evapotranspiration rates and does not properly address all of the factors that determine reasonable use. In addition to climatic, soil and irrigation management factors, it needs to include other factors such as application efficiency, risk and water supply reliability.

A reasonable use test also needs to incorporate assessments for peak system capacity and seasonal water use if minimal adverse effects on source and receiving waters are to be achieved. Appropriate limits can be best achieved by updating current guidelines using computer simulation or by development and use of a more comprehensive decision support system.

In general, although the intent of the standard current ECan consent conditions is to achieve reasonable and efficient use of water, there is no guarantee that efficient and reasonable use will occur in practice. Some of the conditions could result in efficient use of water when measured in terms of application efficiency, which will contribute to a reduction in adverse environmental effects. However, the gains in efficiency will be small.

The conditions can be partially implemented by water users, but cannot be practically and realistically monitored by ECan to ensure compliance.

The conditions relating to monitoring of water takes, with modification, will provide the means to improve irrigation efficiency through better allocation and monitoring. However, the way water is allocated and use is monitored will need to change to obtain the improvements.

Because monitoring of irrigation application efficiency is difficult to do for individual irrigation applications, monitoring of reasonable use can be better achieved by implementing water use metering and use of an alternative definition, as follows:

$$\textit{Seasonal Irrigation Efficiency} = \frac{\textit{Seasonal depth of water applied to crop}}{\textit{Seasonal evapotranspiration} - \textit{Seasonal rainfall}}$$

Consent conditions relating to reasonable and efficient use should include:

- Allowable peak rate of take (in ℓ/s or equivalent);
- Seasonal volumes of water allowed to be taken, based on reasonable use;
- Monitoring to determine peak rate of take at a frequency appropriate to the use of the data and potential effects on the environment;
- A requirement to submit volume of water used each season.

Further ways of using water allocation and the consent process to encourage efficient irrigation are:

- Support initiatives to increase reliability of water supply;
- Encourage design standards and design audits;
- Educate farmers in good irrigation practice, including the advantages of soil moisture monitoring;
- Make greater use of water user groups;
- Promote the use of performance indicators.

Allocating the correct amount of water based on reasonable use in terms of peak rate of take and seasonal use will set the framework for more efficient allocation and use of water.

Because of the impracticality of monitoring the efficiency of individual irrigation events, minimum regulation to ensure peak rates and seasonal use conditions are met, and education of irrigation industry participants (farmers, advisers, designers, equipment suppliers) is recommended as the best means of obtaining efficient irrigation.

1 INTRODUCTION

1.1 Background

Environment Canterbury (ECan) is currently preparing a Natural Resources Regional Plan (NRRP) to manage the natural and physical resources of the region. Part of the Plan will address the management of surface and groundwater resources, and the allocation and use of water from these resources. The NRRP will build on the policies in Canterbury's Regional Policy Statement (RPS), and set out more detailed objectives and policies for setting and managing water allocation.

One of the key considerations is efficient water use. To date, issues relating to efficient and reasonable water use have been primarily dealt with through the resource consent process. There is a need to review this process to enable efficient and reasonable use to incorporate it into the detailed objectives and policies of the NRRP.

1.2 Scope of Project

Irrigation efficiency means different things to different people and is governed primarily by the area of interest. There are many different ways of describing efficiency in terms of the different parts of a water delivery system, including the infrastructure for getting and conveying water, through to the on-farm irrigation system – where, when and how water is applied.

Resource managers are interested in equitable allocation of water, reducing wastage and minimising adverse environmental effects of the take and the use of water. Water supply managers are primarily interested in efficient and equitable delivery of water, and are concerned with distribution system losses. Farmers are interested in maximising profit per unit of water used.

This report focuses on issues related to water use and the efficient application of water. Efficiency is being considered in terms of the relative efficiency of different irrigation systems for applying water to the root zone of plants, while at the same time minimising both poor distribution over the application area and minimising effects on the environment such as losses to groundwater. Wider issues, such as the regional beneficial use of the water, are also discussed to bring the concept of application efficiency into the overall context of irrigation efficiency.

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1.3 Study Objectives

The study objectives are to define terms, to identify what is a reasonable/desirable level of irrigation application efficiency, and to review conditions of water use that:

- ECan can promote as policy in the NRRP. It therefore needs to be robustly founded, e.g. realistic in terms of systems that are available, reasonably achievable, and necessary for promoting sustainable management and good resource management.
- ECan can use, in its reasonable use test assessment of how much water to allocate to an individual wanting a water permit for irrigation and when setting conditions for these water permits.
- ECan can defend as assisting in the fair allocation of the water resource with the least adverse environmental effect.

2 IRRIGATION EFFICIENCY

2.1 Framework for Defining Irrigation Efficiency

There are in excess of thirty definitions of various measures of irrigation efficiency, including several definitions of application efficiency, depending on the area of interest. However, regardless of how irrigation efficiency is defined, there are five basic requirements that an irrigation efficiency definition needs to encompass:

- It needs to be applied to an area with defined boundaries;
- It needs to be considered over a specific timeframe (e.g. an irrigation event or season);
- It is related to the volume of water taken from the source that is beneficially used;
- It needs to take into account soil water storage and effective use of rainfall;
- It should consider all uses within the area, which may include uses other than simply replacing soil moisture deficits.

Beneficial use includes uses such as for crop ET, cooling, frost protection, crop germination, leaching (limited requirement in Canterbury) 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.

Non-beneficial uses are runoff that is not re-used, deep percolation that is not re-used, and evaporation from non-crop areas such as canals or roads and leakage from pipes or canals.

The definition of the boundary area is critical in defining beneficial use (Burt & Styles, 1994). Deep percolation from some areas may be utilised through higher groundwater tables in the lower areas of the same district (e.g. Mayfield-Hinds Irrigation Scheme, Levels Plains Irrigation Scheme). In these cases, irrigation efficiency for the district may be high.

Use of field-scale rather than farm or hydrological boundaries may exclude some beneficial and non-beneficial uses. For example, at the field level, losses from delivery systems and deep percolation, both of which may be beneficial or non-beneficial depending on the circumstances at a specific location, are excluded.

The fifteen most common or widely recognised definitions of irrigation efficiency are described below. For convenience, the definitions have been divided into three groups – *irrigation efficiency*, *application efficiency* and *distribution efficiency* – but it should be recognised that there is significant overlap between the definitions depending on the purpose of the definition.

2.2 Irrigation Efficiency

Many definitions of irrigation efficiency have been reported, but 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.* (1993) 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.

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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.

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

2.3 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 Canterbury) 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:

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

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

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

Commonly, a variation to the above definition is used:

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

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.

2.4 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.

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.

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

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

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

The definition of DU and CU requires 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:

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

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:

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

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.

3 ADVANTAGES AND DISADVANTAGES OF EFFICIENCY DEFINITIONS

The purpose of using a particular definition of irrigation efficiency determines its value. This report focuses on definitions that ECan can promote as policy in the NRRP, that can be used in a reasonable use test for water allocation, and can assist in the fair allocation of the water resource with the least adverse environmental effect.

In selecting an appropriate definition, the time scale (and how a particular definition over that time scale is proposed to be used) is important. Four basic time scales are involved:

- Single (peak) irrigation event;
- Over an irrigation cycle;
- Over an irrigation season;
- Over several years (long-term effects).

3.1 Irrigation Efficiency

In general, definitions of irrigation efficiency (definitions 1-6) have the following advantages:

- The overall water balance is included;
- Area and hydrological boundaries are included;
- Rainfall and soil moisture storage can be included;
- All uses that are beneficial are included;
- An appropriate timeframe is used.

The disadvantages of using definitions 1-6 are:

- Determination of beneficial use in quantifiable or measurable terms is not simple;
- Requirements to meet specific levels of irrigation efficiency will be difficult to measure because beneficial use is difficult to measure.

Irrigation sagacity (IS) (definition 4) is probably a better measure of good water use but, again, determining beneficial or reasonable use is very difficult. Without determining these parameters, the definition cannot be used. In addition, the definition has not been widely accepted or adopted.

Water use efficiency (WUE) (definition 5) 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 on whether the resource has been used effectively.

The advantages of using water use efficiency are as follows:

- Annual production is known;
- Timeframe is usually one season, which is appropriate for production relation definitions;
- If water use is measured, WUE is easy to calculate;
- It provides verification of good practice.

The disadvantages are as follows:

- It varies from season to season, depending on climate;
- It may be highly influenced by production, which is dependent on factors other than water;
- The definition is of most use to water users rather than assessing environmental effects.
- It cannot be readily compared across farms, districts or different systems.

There are two components to this definition – production and water use, both of which are relatively easy to measure. An improvement in WUE can result from increased production or decreased water use, assuming one parameter changes at a time. With intensification and improvements in technology, the trend is for both water use and production to increase as farmers increase production efficiency and profitability. It is a mistake to assume that water use must decrease to improve WUE. This implies that all farmers are using too much water, which may not be true. Increasing WUE will rarely release water for other uses.

Seasonal irrigation efficiency (SIE) (definition 6) has the following advantages:

- Easily calculated, provided that water use and rainfall are measured and ET is available;
- Timeframe is one irrigation season, which is appropriate;
- Takes into account seasonal rainfall;
- Is currently in limited use;
- Gives an indication of reasonable use.

The disadvantages are as follows:

- Requires measurement of water use, rainfall and ET;
- Can vary from year to year because of natural variability of seasonal rainfall;
- Target values have not been widely established;
- Does not take into account beneficial use other than needed to replace ET.

Potentially, this definition is very useful for monitoring as it can be relatively easily calculated. Provided that water use and rainfall is measured, and ET values are available, it gives an indication of reasonable use. It will also give an indication of efficient use because optimum values of the indicator can only be obtained with seasonally efficient application of water.

Although potential ET will be available from regional climate summaries, actual ET will be crop specific. Actual ET will need to be calculated for a range of farming enterprises.

3.2 Application Efficiency

The advantages of application efficiency (definitions 7-11) are:

- Can be easily applied to climatically determined design water requirements to determine on-farm irrigation system design capacity or water allocations;
- Generally widely accepted (with variations);
- Average depth of irrigation applied can be reasonably easily measured.

The disadvantages are:

- Water delivered to field is not widely measured in Canterbury, although that can be rectified by water metering;
- Water stored in root zone or used by crop is very difficult to measure;
- Values change with every irrigation event – timeframe is short;
- It does not account for all of the beneficial use of the water;
- It does not consider hydrological boundaries outside of the field, if wider boundaries are being considered;
- It does not take into account effective use of rainfall.

Application efficiency definitions imply that if the majority of water delivered to a farm was stored in the root zone of a crop, application efficiency would be high. This can be achieved by applying relatively small amounts of water to soils with high soil moisture deficits, but the goal of irrigation, which is to obtain optimum productivity, is not met. High application efficiency does not necessarily mean high water use efficiency. Conversely, low application efficiency (by applying large amounts of water to soils with low soil moisture deficits) will result in sub-optimum production and, almost certainly, low water use efficiency.

It is impractical to accurately measure water stored in the root zone over a field. Soil moisture measurement is commonly used to provide values at measurement locations. Given the wide variation in soil water holding capacities, soil depths, crop water use and application depths, a true measure of water stored in the root zone is difficult to obtain. Despite its limitations, soil moisture measurement is one of the best methods of providing information to farmers that enables them to manage irrigation applications to achieve both high application efficiency (providing the irrigation system has that capability) and high water use efficiency.

A major attribute of application efficiency is that it is specific to conditions applying at the time of irrigation.

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

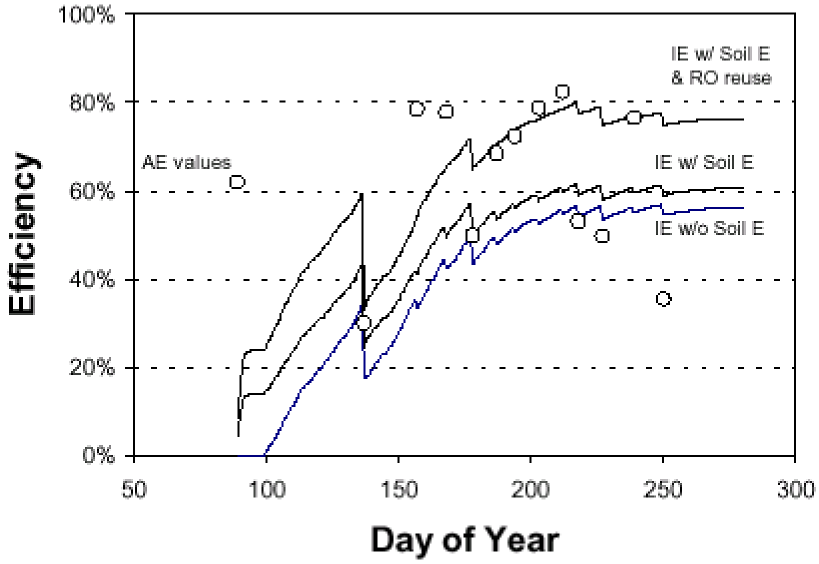

Figure 1: Calculated efficiencies for irrigation on grower's field for 1994 (Hunsaker et al., 1999)

The three curves plotted are irrigation efficiency (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, 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. Treating soil evaporation as non-beneficial lowers both irrigation efficiency and beneficial use if basal transpiration alone is regarded as beneficial.

Application efficiency (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 lower 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.

3.3 Distribution Efficiency

Uniformity of irrigation application is one of the main limitations of efficient irrigation. Definitions 12-15 are associated with application uniformity.

These definitions are extremely useful to irrigation designers to ensure that systems are designed to a desired level of uniformity. Poor design uniformity almost always leads to low application efficiency as definition 12 shows.

Calculation of application uniformity from equations associated with distribution or emission uniformity is outside the scope of both farmers and ECan staff. Significant design experience is needed to make these assessments. For this reason, these definitions cannot be recommended for general use as methods to assess efficient irrigation.

If design standards are implemented in New Zealand (this is currently under consideration by the New Zealand Irrigation Association (NZIA)), then required measures of application uniformity will be included in those standards.

4 APPROPRIATE LEVELS OF EFFICIENCY

4.1 Types of Irrigation Systems Used in New Zealand

The types of irrigation systems typically used in New Zealand are listed below. These have been divided into groups as used in the New Zealand Irrigation Manual (Malvern Landcare, 2001). Where spray irrigation systems can be fitted with a range of sprinkler types that are likely to result in different application efficiencies, they have been listed separately.

Surface irrigation

- Border-strip
- Contour irrigation
- Wild flooding

Border-strip irrigation is the most common surface irrigation method used in New Zealand.

Travelling irrigators

- Rotary booms - medium pressure
- Fixed boom
  - low pressure spray jets
  - mini sprinklers
  - impact sprinklers
  - multiple guns
- Centre-pivots
  - low pressure pivot sprays and spinners
  - rotating type pivot sprinklers
  - impact sprinklers
- Linear moves
  - low pressure pivot sprays and spinners
  - rotating type pivot sprinklers
  - impact sprinklers
- Hard hose guns
  - high pressure gun
  - low-medium pressure boom
- Travelling guns - high pressure

Manual move systems

- Hand shift/end tow
- Side rolls
- Long lateral and variants
- K Lines and variants

Fixed systems

- Solid set
  - small rotating sprinklers
  - medium pressure impact sprinklers
  - high pressure guns
- Minisprinkler
- Microsprinkler
- Microjet
- Drip
  - drippers
  - drip tape
  - sub-surface drip tape

Most landscape/turf and amenity watering systems are fixed systems, although some utilise small travelling irrigators.

4.2 Application Efficiency Information (New Zealand)

A limited amount of verifiable information is available on application efficiencies measured under New Zealand conditions.

Research into irrigation efficiency was started at Winchmore Irrigation Research Station in 1968 and continued through to 1977. However, published results of that research has not been sourced.

A Technical Handbook, Advisory Services Division, Volume 2, Ministry of Agriculture and Fisheries (1971) 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.).

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 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). Application efficiency (Table 1) has been calculated using the relationship developed by Seginer (1987).

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

From definition 13:

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

From definition 14:

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

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

As part of a best management practice research project for irrigation, Lincoln Environmental, over the 1997 and 1998 irrigation seasons, measured application efficiencies (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 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.

On the rotary boom system, application efficiency was measured in excess of 90% when 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 and some loss of yield may have occurred.

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. There is some concern that best-practice irrigation was not performed on these properties and the low values measured are not representative of what could be achieved. Evans states that the nature of the 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) are slightly better than the soils described in Evans.

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 on-going research at Winchmore, has measured application efficiencies under a range of sprinkler and border-strip irrigation types. However, the analysis of the data has not yet been completed. The results will be published after completion of the research.

Application efficiencies (Table 2) have been calculated from measured water use data over the 1998/2000 irrigation seasons (A Daveron, Hydro Services Ltd, pers comm.). These values were obtained from soil moisture measurements taken over each irrigation season.

Table 2: 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 has an influence on application efficiencies. Using the same data set, the following was found:

Table 3: 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.

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.

4.3 Application Efficiency Information (International)

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 4. These values are intended for general system type comparisons and should not be used for specific systems.

Table 4: 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.

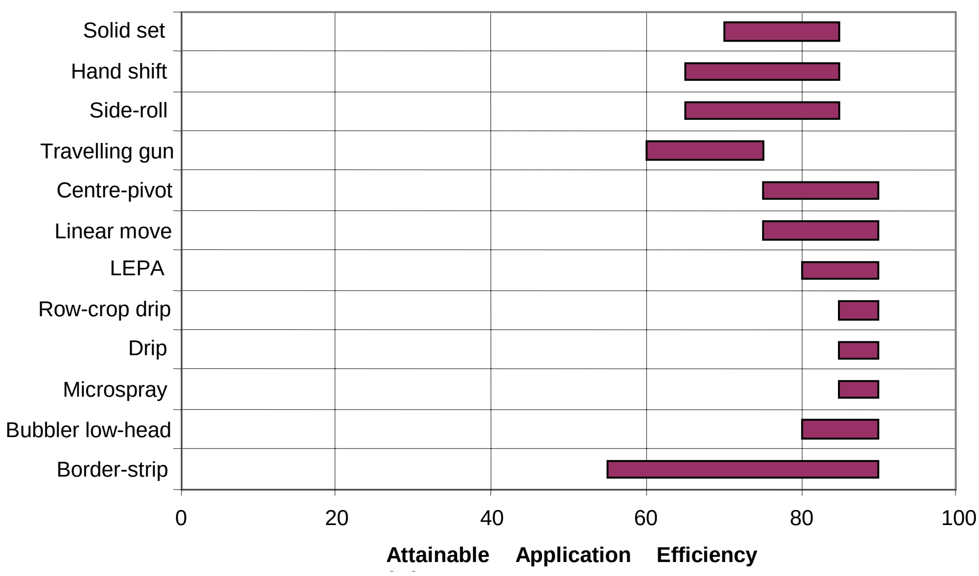

Figure 2: Attainable application efficiencies for different system types

4.4 Key Factors Affecting Efficiency

Efficient irrigation depends on:

- The design of the system
- How well it is managed

Design sets the platform for efficient irrigation. If a system is poorly designed, efficiency will be low. If a system is properly designed, the potential for high efficiency exists; but whether it is achieved or not depends on how well the system is managed.

To determine where the focus on irrigation should be to improve application efficiency, it is necessary to examine where losses occur. The water losses expected on typical irrigation systems in New Zealand are as follows:

Table 5: Expected water losses on spray irrigation systems

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-irrigation areas	0-5%	<2%
Interception	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.

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).

Some of the losses are visible – leaking pipes, water blown away by wind, watering non-irrigation areas and surface runoff. Others are not visible – evaporation, interception, uneven or excessive application. The focus for improving efficiency is often in the wrong areas (i.e. on the visible rather than non-visible factors).

The greatest potential for loss is due to uneven application, which is largely a design issue and excessive application, which is largely a management issue, but can also be due to inflexible design. Uneven application can result from poor distribution uniformity caused by wind or by substandard sprinkler distribution patterns. It can also be caused by excessive application rates causing surface redistribution.

Losses from trickle systems usually occur from runoff, soil evaporation or deep percolation. However, drainage normally limits application efficiency, as runoff and soil evaporation is small or non-existent.

Although the minor losses (leaks, evaporation, watering non-irrigation areas, runoff) are important and should not be ignored, the focus needs to be on improving distribution uniformity and irrigation management if application efficiency is to be substantially improved.

It is important to recognise that virtually all sprinkler and trickle irrigation systems have the potential to be operated to apply only that water that is needed (i.e. high application efficiency). With the increasing flexibility offered by the more modern irrigation systems, the correct application of water to soils with low water holding capacities can be more easily accommodated than before. However, on older systems, applying small depths of water to maximise application efficiency will probably compromise overall system capacity and reduce water use efficiency. This is because of the need for more frequent moving of equipment and the higher "down time" involved.

5 REASONABLE USE TEST

5.1 Current Method of Assessing Reasonable Use

The current assessment of a reasonable daily application rate (mm/d), used by ECan in consent applications, considers the following factors.

[a] Main soil type

ECan usually obtain this information from NZLRI or similar soil maps. Often, this differs from the soil type given by consent applicants. It needs to be recognised that the soil maps are generally "broad-brush" with very fuzzy boundaries between different soil types. It is not uncommon for actual soil types in the field to vary from that given in the soil maps. In terms of the current process of determining reasonable use, the actual soil type is primarily used to determine the average water holding capacity of the soil.

[b] Average water holding capacity

Although soils databases do give water holding capacities, these vary by wide ranges in the field in practice. Soils are far from uniform on any property. For arable crops, water holding capacity depends on crop root depths, which in turn depends on growth stage. Pasture root depth, although less likely to change over short time periods, also varies. Often, maximum root depths (and therefore maximum water holding capacities) coincide with periods of maximum ET.

Determining an average water holding capacity from soil maps is a best estimate that is appropriately used in the absence of additional, more reliable information.

[c] Minimum amount of water needed in root zone

For crops where the root depth varies, the minimum amount of water needed in the root zone also varies. It also varies according to crop type, the quality of crop required, and the ET rate on a particular day. Generally, the higher the ET rate, the lower the allowable deficit. That is why soils can be allowed to dry out more for spring crops (e.g. peas) and autumn crops (greenfeed, late crop potatoes) than for summer-peaking crops such as pasture or main crop potatoes.

Although a 50% depletion is normally allowed, the required value can vary from 30-70%, depending on crop type, soil type and time of year.

[d] Application depth (the difference between [b] and [c])

Accepting that there is a significant amount of uncertainty in the [b] and [c] values, the difference between the two is the theoretical maximum depth that should be applied. Because of the non-uniformity of irrigation system application, 50% of the water applied will exceed this value and 50% will be under this value, assuming no other losses such as evaporation in the air occur.

[e] Average daily ET

The length of time over which ET is averaged is not specified. The implication is that it is over the irrigation season at 5 or 6 mm/d, but what is probably intended is peak ET averaged over the return interval. The shorter the short return interval, the higher the average ET over peak periods.

Two approaches could be taken to determine peak reasonable use. One approach is to use peak ET averaged over the expected system return interval. This approach excludes the effect of rainfall, system type, crop type and soil type. The second approach is to use the design ET rate, which is based on meeting a proportion of total ET over the return interval. The design ET rate is a function of climate (ET and rainfall), crop type, soil characteristics, system efficiency, system cost, and the risk of not fully meeting crop water demand. The optimum rate to use for design (e.g. 5 mm/d) has been largely determined by a combination of computer water balance modelling and practical experience.

Design ET rate is often expressed in terms or irrigation system capacity (litre per second per hectare), which is a more appropriate method of assessing reasonable use in terms of peak daily rate.

[f] Return interval

This is commonly taken as the number of days between irrigation applications, and is either the minimum number of days between irrigation applications that the irrigation system is capable of achieving or the expected number of days that the system will be operated over. Many irrigation systems today (e.g. fixed centre-pivots) have the physical capability to apply small amounts of water daily, but are operated on a 3- to 5-day return interval to obtain optimum overall efficiency.

[g] Reasonable rate

Because of the way this is calculated in the consent application form, it is always equal to the average daily ET (except for the small rounding associated with the number of days), so the step is superfluous.

The “reasonable” rate is essentially the average daily ET assumed in step [e]. Whether it is in fact “reasonable” depends on how the average daily ET was determined. None of the steps [a] to [f] address that issue. In fact, steps [a] to [d] and [f] are addressing the issue of efficient use, not reasonable use.

5.2 Determining Reasonable Use

The reasonable rate currently used by ECan does not specially allow for efficiency. When applications are submitted for this rate, it should be clearly understood that the effective amount of water available to the crop is less than this amount. That is the current approach, although it is unlikely that many farmers, when applying for water, are aware of that. The advantage of the approach is that it is simple. The disadvantage is that an assessment of an appropriate rate needs to be made.

If reasonable rate is understood to include any losses that may occur, then it is not necessary for the applicant to allow for irrigation system type. However, an assessment of what those losses could be and adjusting ET rates accordingly, has to be made to determine whether or not the rate is reasonable.

The preferred method to determine reasonable use (measured in terms of peak rates and seasonal use) is to computer simulate irrigation demand using daily climatic records over as many years as possible. Ideally, simulations should incorporate the operational side of irrigation (depths of water applied, return intervals, uniformity of application and risk), as well as climatic demand into the calculations.

Table 6 provides an example of reasonable peak rates for pasture based on fully meeting demand 90% of the time with an assumed application efficiency of 80% (adapted from LE, 2000).

Table 6: Reasonable peak allocation rates for pasture

Rainfall station	**Soil water holding capacity (mm)**	**System capacity required to meet 90% of ET demand**	
		(ℓ/s/ha)	**(mm/d)**
Coldstream	60, 90, 120	0.60	5.1
Winchmore	60, 90	0.60	5.1
	120	0.58	5.0
Highbank	60, 90	0.58	5.0
	120	0.55	4.8
Alford Forest	60, 90	0.55	4.8
	120	0.40	3.5

Using peak rates as the only basis of allocating water allows water to be abstracted, at least in theory, for 365 days per year. Practically, this does not happen and seasonal use is much less than the theoretical volume.

Computer simulation used to provide information for reasonable peak allocation rates can also be used to provide information for reasonable seasonal water use. Table 7 provides an example of reasonable seasonable use for pasture based on fully meeting demand 90% of years with an assumed application efficiency of 80% (LE, 2000). Unlike peak use, which is strongly driven by ET rates, seasonal use is more sensitive to rainfall and the ability of soil to store rainfall.

Table 7: Depth (millimetres) required to fully meet seasonal demand in 90% of years

Soil WHC	**Rainfall station**			
	Coldstream	**Winchmore**	**Highbank**	**Alford**
60 mm	902	817	706	630
90 mm	741	692	567	485
120 mm	672	619	522	420

6 EFFICIENT USE CONDITIONS OR STANDARDS AND TERMS

The key issues that have to be considered when assessing the appropriateness of consent conditions are:

- Will the conditions result in efficient use of water?
- Will the conditions reduce or prevent adverse environmental effects?
- Can the conditions be easily implemented and monitored by water users?
- Can the conditions be monitored by ECan staff to ensure compliance?
- What effect does the condition have on farm production and profitability?

These issues are addressed for each consent condition listed below.

6.1 Comment on Consent Conditions – Environment Canterbury (ECan)

Condition 1(a)

1. *To ensure water abstracted under this consent is used efficiently, the consent holder shall, at the start of each growing season, investigate, identify, implement and record all practicable water conservation measures, including, but not limited to:*
   a) *ensuring that the volume of water applied does not exceed that required to return the soil to field capacity*;*

*(*For the purposes of this condition, **Field Capacity** is the soil moisture content after the soil has been fully saturated and allowed to drain freely under gravity for 24 hours.)*

This condition can be interpreted in two ways, each with very different results.

One interpretation is to treat field capacity as a definition describing a state of soil moisture and nothing more. The implication of this is that any water applied should never exceed this value.

The second interpretation is to assume that to reach field capacity, the soil could be fully saturated and allowed to drain freely under gravity for 24 hours. On this basis, it allows for losses from the soil and, depending on the soil type and application depths, significant losses could occur. If field capacity has not been defined, this interpretation would not have been valid.

If Condition 1(a) could be implemented without losses to groundwater, it could result in an increase in efficient use of water in so far as application efficiency is concerned. If losses to groundwater occur, it may assist in the efficient use of water when considering beneficial use or the wider regional effects. Under the condition, there is no guarantee that irrigation applications will be efficient.

The condition could reduce adverse environmental effects, such as leaching of nitrates and pesticides to groundwater, if it achieves application without losses to groundwater. However, it must be recognised that irrigation in general substantially increases drainage due to rainfall compared to that occurring on non-irrigated land. The reduction in drainage that could be obtained by increasing application efficiency will be a small percentage of the combined drainage due to rainfall and irrigation that would have occurred in any case.

Surface irrigation (e.g. border-strip irrigation) almost always results in drainage through the root zone due to rapid preferential flow. Despite this occurring, the soil is not necessarily returned to field capacity.

An improvement in application efficiency could reduce the effects of taking water on the water source, as long as the improvement in efficiency resulted in less water being taken. A reduction in take does not usually occur with an increase in efficiency because most irrigation systems are under capacity and the increase in efficiency is used to obtain more optimal production rather than to reduce take.

The condition could also compensate for adverse environmental effects if losses from irrigation increase groundwater quantity, supplementing groundwater-fed streams or rivers.

Practical issues relating to Condition 1(a) are as follows:

- Most irrigation systems are under-capacity (i.e. do not have the peak capacity to meet high ET periods). Where capacity is limited or where water restrictions are likely, it is necessary to maintain soil moisture levels close to field capacity so that when ET exceeds capacity, moisture levels are as high as possible leading into the peak of the season. This puts them in a state to "ride out" the extra demand without significant production losses.

- All irrigation systems apply water non-uniformly, so even if application depths were carefully managed to replace the average soil moisture deficits, some parts of the field will receive more water than the deficits allow. For example, Table 1 shows that for rotary boom irrigators with a CU of 75%, an AE of 88% is achieved, meaning that 12% of the applied water is lost due to deep percolation (i.e. exceeding field capacity).

- Soil water holding capacity, soil moisture status, crop root depths and crop water use varies significantly throughout a field both spacially and over time. Trying to quantify this variability is virtually impossible to the extent required to apply water and not exceed field capacity.

- Field capacity, as defined above, is a concept that is commonly used but is often a short-term transient state in Canterbury soils. On light soils, it may occur several hours after irrigation. On heavy clay soils, it may occur several days after irrigation.

Condition 1(a) is very difficult for farmers to monitor in practice. The condition is also virtually impossible for ECan to monitor, particularly over a large scale. Staff would have no practical way of measuring or ensuring that farmers carry out what is required to meet the condition.

Condition 1(b)

1. *To ensure water abstracted under this consent is used efficiently, the consent holder shall, at the start of each growing season, investigate, identify, implement and record all practicable water conservation measures, including, but not limited to:*
   b) *the maintenance of works, pipes and structures forming part of the abstraction and conveyance system to a safe and serviceable standard, to minimise leakages;*

This condition addresses losses normally associated with irrigation efficiency rather than application efficiency.

Maintaining works, pipes and structures forming part of the abstraction and conveyance system to a safe and serviceable standard, to minimise leakage, is reasonable. Keeping an irrigation system in a good state of repair is part of a best practice approach that farmers should be taking. It will result in more efficient use of water. However, in terms of overall loss, leakage tends to be small, so changes in efficiency will be small.

The condition could also reduce or prevent adverse environmental effects such as reducing drainage to groundwater at the leakage points.

Leakage from pipes is easy to see if it occurs above ground. It is not so easy to identify if it occurs below ground and yet the majority of pipeline leaks occur below ground. These leaks are identified by unexpected wet spots in fields or water bubbling to the surface, and are eventually noticed by farmers and repaired.

Condition 1(b) is achievable but, again, difficult for ECan staff to monitor to ensure compliance. User self-monitoring, with follow-up from monitoring staff to reports of leakage, would be a reasonable expectation.

Condition 1(c)

1. *To ensure water abstracted under this consent is used efficiently, the consent holder shall, at the start of each growing season, investigate, identify, implement and record all practicable water conservation measures, including, but not limited to:*
   c) *avoiding the irrigation of waste areas such as impermeable surfaces, unproductive land and river and stream riparian strips.*

Avoiding the irrigation of waste areas such as impermeable surfaces, unproductive land and river and stream riparian strips, is also reasonable and desirable but not always achievable. It requires a system to be designed and managed to avoid watering waste areas. Irrigating in windy conditions will often result in some watering of unproductive areas. Most systems do not have the capacity to catch up if turned off during windy periods, and most farmers take the approach that it is better to get some water on to target areas than none at all.

If achieved, it will result in more efficient use of water, but as with leakage, loss of efficiency caused by watering of unproductive areas tends to be small.

The condition will reduce or prevent adverse environmental effects to a limited degree.

Farmers can take practical steps to operate their irrigation systems to minimise the irrigation of non-productive areas but it is difficult to totally avoid this occurring in all circumstances.

As with the previous condition, Condition 1(c) is achievable but, again, difficult for ECan staff to monitor to ensure compliance. User self-monitoring, with follow up from monitoring staff to non-compliance, would be realistic.

Condition 2

2. *When requested by the Canterbury Regional Council, the consent holder shall, within six months of the request, install, or provide for the installation of:*
   a) *an easily accessible straight pipe, of a length at least 15 times the diameter of the pipe, or*
   b) *a water flow measurement device which will measure the rate at which water is taken to within an accuracy of 10 percent,*

   as part of the pump outlet plumbing or within the mainline distribution system.

Water metering is vital if water resources are to be managed sustainably. However, under the current method of allocating water, where peak flow rates or volumes taken over short periods are specified, water meters have limited value.

Condition 2(a) is reasonable for new systems as it allows for installation of in-line water meters or for use of external meters for monitoring. This should improve allocative efficiency of the water because actual takes can be recorded and used for overall resource management (lack of accurate water-use figures is one of the greatest difficulties in water management planning). It can also increase application efficiency because farmers can use the data to better manage their irrigation systems – they will know how much water is applied and when. It also allows indicators of sustainable agriculture to be determined to improve overall irrigation performance.

On new irrigation systems, the condition can be reasonably easily implemented. The difficulty with the condition for existing systems is that most pipe layouts from pumps do not have the necessary length of straight pipe at a location that can be used for flow metering. If standard flow meters are to be installed, major modifications of headworks is necessary.

The condition can easily be monitored by ECan staff through a routine field visit. For existing systems, some flexibility around the 15 diameters should be allowed as the loss of accuracy by installing in-line water meters in 10 diameters, for example, will generally be well within the required accuracy of 10%.

The intent of Condition 2(b) is also reasonable. However, the wording needs to be changed to clarify the intent, to broaden the scope of measuring devices that can be used, and to not preclude new technology developments.

Most flow measurement devices do not measure flow rates directly. Standard flow meters measure volumes of water passing through them and do not record time so that flow rates cannot be automatically determined. Other meters measure velocity, pressure, electricity use or any other parameter that can be correlated to flow rates and volumes. The condition needs to clearly specify the information required, which will depend on the purpose of the information. The accuracy of the information must be specified and evidence provided to show that the specified accuracy is likely to be achieved. An accuracy of 10% should be easily achievable by most metering methods.

For river takes, flow rates (litres/second) determined hourly and volumes of water (cubic metres) taken seasonally could be specified.

For most groundwater systems, frequent monitoring of maximum pumping rates is of less importance provided that volumetric limits are met. Maximum pumping rates measured as soon as possible after consents have been exercised and subject to random checks would meet most purposes. More importantly, monitoring of volumes of water (cubic metres) taken weekly or monthly, could be required.

The length of straight pipe will allow ECan staff to determine the accuracy of measurement and to cross-check meter readings using external devices such as ultrasonic flow meters. It needs to be noted, however, that the relevance of the check depends on the accuracy of the checking devices, which can be subject to inaccuracy.

Condition 3

3. *When requested in writing by the Canterbury Regional Council, the rate at which water is taken shall be measured to within an accuracy of 10 percent, and the measurement and the hours during which water is taken shall be recorded. A copy of the records shall be provided to the Canterbury Regional Council in accordance with the request.*

Condition 3 logically follows Conditions 2(a) and 2(b), and is largely a matter of policy. However, the wording needs to be modified to accommodate the issues discussed for Condition 2(b).

6.2 Comment on Conditions – Environment Waikato (EW)

Condition (a)

a) *That water shall not be applied at a rate which exceeds the water holding capacity of the soil within the plant root zone (rhizosphere).*

The intention of Condition (a) is similar to ECan Condition 1(a), and similar comments apply. The use of the word "rate" is surprising as it is also used in Condition (b) in a totally different context. Taken literally, the condition is meaningless as it compares a rate with a volume. Rate refers to a depth of water applied over a specific time. Water holding capacity refers to a depth or volume of water. The condition should refer to "depth" or "volume" as the ECan condition does, not "rate".

Condition (b)

b) *The rate of irrigation shall not exceed the infiltration rate of soil or cause any run-off or ponding of irrigated water.*

This condition uses the term "rate" correctly, although it should be "application rate". If full compliance of this condition was obtained, application efficiency would be improved as water applied at rates that exceed the infiltration rate of the soil, causing ponding and runoff is a significant cause of non-uniform irrigation and lower application efficiency.

The comments for ECan Condition 1(a), relating to reducing or preventing adverse environmental effects, also apply to this condition.

Meeting the terms of the condition is very difficult. Almost all irrigation systems cause some ponding because they apply water at a rate that exceeds soil infiltration rates. Infiltration rates change over time according to soil structure, surface condition and soil moisture content. Generally, the instantaneous application rates under New Zealand spray irrigation systems always exceeds soil infiltration rates (John *et al.,* 1985). Micro-storage (water stored in small indentations at the soil surface) is necessary to average out the instantaneous application over a longer time interval. Average rates may or may not exceed the infiltration rate of soils. For example, instantaneous application rates under a big gun were measured at up to 600 mm/h by John *et al.*, while average rates were as low as 9 mm/h. This illustrates the importance of some storage/ponding on the soil surface.

Ponding in itself is not a problem, providing the ponded water does not redistribute significantly over the field. In fact, some ponding is necessary to smooth out instantaneous application rates. Problems occur when the ponded water runs from high spots into low spots or, in serious cases, off the field altogether.

Farmers can usually observe runoff and take steps to minimise it. Eliminating runoff altogether is very difficult and may require a totally different irrigation method. It can be monitored at least qualitatively and moderated through changes in irrigation management, but it will be impractical to meet the terms of the condition as written.

User self-monitoring, with follow up from monitoring staff to non-compliance is all that could be realistically achieved.

ECan does not have a specific condition corresponding to EW Condition (b). It could be included in a range of practical water conservation measures.

Condition (c)

c) *As a result of the use of water for irrigation there shall be no more than a 10 percent increase in annual peak background nitrate-nitrogen in groundwater.*

This condition creates several issues that make it difficult to implement and difficult to monitor:

- There is no indication of what "annual peak background nitrate nitrogen levels" means. Presumably, it is related to concentrations of NO_3 (g/m^3) in the groundwater.
- The allowable 10% increase means that the higher the background levels, the higher the allowable increase. This is usually the reverse of what is allowed.
- There is no upper limit set on levels.
- How background levels are defined and measured is not clear. Who is responsible for providing the peak background levels?
- Attributing the result of the use of the water to increases in nitrate levels on specific properties is often difficult, if not impossible to do accurately, given the uncertainty in the system.

It is difficult to see how this condition will result in efficient use of water.

It is also difficult to see how the condition will reduce or prevent adverse environmental effects when the higher the level, the higher the allowable increase.

The condition cannot easily be implemented or monitored by the water user. It is extremely difficult to prove cause and effect when so many factors influence N concentrations. Water quality monitoring can provide some indication of system response, but for non-point contamination of groundwater, modification of management practices is usually needed over a broader scale than an individual property.

ECan could easily monitor groundwater quality (or require water users to provide the data), but associating a particular change in nitrates to a specific property will be difficult in many areas.

7 DISCUSSION

7.1 Irrigation Efficiency Definitions

There are in excess of 30 definitions relating to irrigation efficiency. The most common of those definitions have been described in Sections 2 and 3 of this report. The fact that there are so many definitions strongly suggests that there is no easy answer to selecting an appropriate single definition and assigning suitable values to it.

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).

The time scale is important. The three basic time scales involved are:

- Single (peak) event
- Over one irrigation cycle
- Over a season

At the single peak event level, efficiency definitions relating to design or hydraulic issues are of most use. These efficiency values are of most concern to designers when sizing components and selecting systems to meet the level of performance required. Other than maximum (or design) demand, there are no management or climate issues considered.

Over the irrigation cycle, irrigation management plays a part in trying to match application to actual irrigation demand and to make best use of rainfall. Normally, definitions that incorporate actual water applied and a measure of beneficial use, such as replacing ET, are required.

The overall seasonal performance, which is the most important measure to describe irrigation efficiency, incorporates all beneficial use, production-based measures or seasonal evapotranspiration and rainfall.

For surface water supplied systems, the peak rate of take (e.g. in m^3/h) is important because it has a direct effect on the water source, so needs to be controlled over a short timeframe. Excess irrigation from surface supplied systems results in drainage to groundwater that may be beneficially used elsewhere over a much longer timeframe.

Of the fourteen definitions described, four definitions have the potential to meet ECan's requirements in terms of water allocation, reasonable use and efficient use. They are:

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

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

$$ISE = \frac{\textit{Water stored in crop root zone}}{\textit{Total amount of water delivered to the farm}} \quad (10)$$

$$AE = \frac{\textit{Water stored in crop root zone}}{\textit{Average depth of water applied to crop}} \quad (11)$$

Definition 6 is of most benefit to assess reasonable water use over a season where the purpose of irrigation is to replace water lost by evapotranspiration and where seasonal water allocations have been implemented. High values of SIE (e.g. 1.5 or higher) indicate that significantly more water than that required to replace ET has been used. Low values (<1) indicate that under-irrigation or partial irrigation has occurred.

Although of most use for single events, definition 8 can be used to assess reasonable use over a season by accumulating all beneficial uses over a season. Indicative values are difficult to provide because the values depend on what the target is. If the target is limited to replacing ET, then values similar to those given for definitions 10 and 11 would be appropriate.

Definitions 10 and 11 are similar in concept because both have the target as water stored in the root zone. Definition 10 allows for losses in the irrigation distribution system, which for piped systems should be minimal. For open channel systems, 5-15% losses are typical. These two definitions are of most benefit to assess the application efficiency of individual irrigation events.

7.2 Appropriate Levels of Application Efficiency

It is clear from the irrigation application efficiency values described in Section 4, that application efficiency varies over quite a wide range depending on crop type, irrigation system type, and the standard of irrigation management that can be achieved. Soil type is also probably influencing the results, especially for surface irrigation methods, but has not been stated for the data described in Section 4.

The international data shows that, on average, some system types appear to be more efficient than others; for example, centre-pivots and trickle irrigation appear to be capable of achieving higher efficiencies than travelling irrigators. The data also shows that border-strip irrigation has the potential to be as efficient as spray irrigation.

In New Zealand, based on the limited data available, there appears to be less difference between the various spray irrigation types, but a greater difference between border-strip irrigation and spray irrigation. This is most likely due to the significant proportion of border-strip irrigation that occurs on soils with low-medium water holding capacities in New Zealand, compared to other countries.

The data shows that an application efficiency of 80% (based on definition 11) could be achieved on well-designed and well-managed spray and drip irrigation systems. Although wide ranges of application efficiency have been measured, all systems – except perhaps travelling guns (based on the international data) – can achieve 80% application efficiency. Many systems routinely achieve higher than 80%. Crop type appears to have a minimal effect on achievable application efficiency. The New Zealand data shows that irrigation of dairy pasture has, in the past, achieved lower efficiency than irrigation of other crops, but this is likely to be irrigation management related rather than that due to differences in system or crop type. There is little justification for applying different application efficiencies to system type or crop type.

A reasonably achievable level of application efficiency for surface irrigation is more difficult to specify for New Zealand conditions because achievable efficiencies are highly dependent on site specific conditions, such as border flow rates, crop resistance, soil infiltration rates and border design. A wide range of values has been measured in New Zealand and internationally. Values of 40-60% should be achievable on well-designed and well-managed systems. Currently, many border-strip irrigation systems are being re-graded, with higher border flow rates being used. Efficiencies approaching 80% have been reported by some farmers, based on calculating hectares per hour watered, but these figures have not been verified.

Although water could be allocated on the basis of 80% application efficiency for spray and trickle systems and 50% for surface irrigation systems, there is merit in treating all systems the same way. This would mean that border-strip irrigation systems would receive no more water than spray methods. The choice would rest with the irrigator as to which method is used. Administratively, using a single application efficiency value is also preferred, because if farmers change from a less efficient system to a more efficient system, the amount of water allocated would not change.

Choice of a less efficient method may be justified on farm economic grounds, but where water is limited in its availability, allocating water based on lower efficiency will limit regional benefits. Although application efficiency does not take into account the wider hydrological boundaries that occur under most irrigation schemes, drainage to groundwater on irrigation systems that are 100% efficient will increase due to rainfall. An 80% efficiency will provide for even greater movement of water to groundwater. However, where there are measurable beneficial effects to groundwater from less efficient irrigation methods, lower application efficiencies may be justified.

7.3 Effect of Application Efficiency on the Environment

How efficiently irrigation systems apply water has two main environmental effects. The first is on the source of water (i.e. whether the water is sourced from storage-based systems such as groundwater or lakes, or flow-based systems such as rivers or streams). The second is on the receiving water, which is usually groundwater, although some water may eventually end up in surface water resources.

7.3.1 Groundwater as a Source

Pumping groundwater may result in lowering of groundwater levels affecting other water users or spring-fed streams in lowland areas or, in serious cases, a long-term decline in water levels. When irrigation occurs with low application efficiency (definition 11), the excess water applied drains through the soil profile to the underlying aquifers. Whether or not this water is "lost" depends on whether it can be beneficially used elsewhere in the hydrological system.

Because of the inter-connection between the various aquifers in Canterbury, the “lost” water has the potential to be re-used.

Regardless of how much water is pumped, the maximum amount of groundwater that is actually used (i.e. taken out of the hydrological system) is the additional crop consumptive use due to irrigation (and a very small amount of evaporation in the air for sprinkler systems, which can be ignored). This actual use is approximately equal to the difference between ET under irrigated conditions and ET under dry land conditions. In addition, drainage under irrigated areas is always significantly higher than under dry land areas because of the effect of rain falling on moist soil, even on systems with very high application efficiencies. Actual groundwater use, therefore, is independent of irrigation application efficiency. It is dependent on the area irrigated and irrigation system capacity. Irrigation system capacity that is insufficient to fully replace ET will result in lower overall water use. In volumetric terms, the actual groundwater use is significantly less than the amount of water pumped.

If pumping rates are increased above that required for reasonable use to compensate for inefficient application, there could be increased short-term interference effects on neighbouring wells or rivers, or water draining to higher or different aquifers than from where it was taken, because of the higher rates pumped. In practice, this rarely happens. Pumping rates are usually governed by well capacity, with capacity rarely greater than that desirable for reasonable use. Although inherently, reasonable use may have an allowance for application efficiency built in to it, it is rare for pumping rates to be adjusted to account for the application efficiencies of different irrigation methods. The exception may be for border-strip systems, but groundwater-sourced systems using border-strip irrigation are very uncommon.

Inefficient systems may be operated for longer to compensate for the additional loss to groundwater. This may increase interference effects on neighbouring wells in situations where the additional drainage does not cause a rise in groundwater levels of the pumped aquifer.

Overall, quantity issues related to application efficiency on groundwater-sourced systems are likely to be minor. However, from a farmer’s perspective, inefficient irrigation will affect irrigation performance and on-farm production and profitability.

7.3.2 Surface Water as a Source

If water is allocated on the basis of peak take alone, the flow rate effect on a surface water source, such as a river or stream, depends primarily on how the peak take was determined and whether that rate includes an allowance for application efficiency or not. If ET rates are adjusted for application efficiency, low application efficiency will require higher peak takes from the source, resulting in potentially greater effect on the source. If there is no volumetric limit on the total quantity of water taken, the effect of inefficient irrigation will also increase the amount of time that water is abstracted from the source. This is assuming that additional water at the peak rate is taken to make up for the deficiency arising from inefficient irrigation.

Whether application efficiency has an effect on the source of water, such as a river, depends on how water is allocated. If it is allocated on the basis of reasonable use over a season, inefficient irrigation will primarily affect irrigation performance and on-farm production, provided that the total volume and the peak take are controlled.

7.3.3 Effect on Receiving Waters

Application efficiency affects the amount of water draining through the soil profile and the quantity of contaminants entering the groundwater system. For groundwater sourced systems with low application efficiency, this will result in an increase in contaminant concentration in most groundwater systems in Canterbury. Systems with higher application efficiencies will reduce the mass balance of contaminants entering the groundwater systems.

For irrigation systems that are being supplied by water from a river, the net actual use of water by the crop is the same as for groundwater-supplied systems. However, inefficient application increases the amount of water from an external source draining to groundwater. The additional drainage may be beneficial or non-beneficial. It may be beneficial if it reduces the concentration of contaminants in groundwater through dilution, which is possible if the quality of source water is high. It could also be beneficial if the additional drainage contributes positively to groundwater access or environmental enhancement such as the maintenance of flows in spring-fed streams or rivers. It will be non-beneficial if it is not used, if it increases contaminant concentrations, or it causes problems such as high water tables.

7.4 Reasonable and Efficient Use

From a farmer's perspective, reasonable irrigation capacity depends on:

- Climate (ET and rainfall)
- Soil parameters
- Crop type
- Irrigation method
- Irrigation management
- Risk
- Water supply reliability

Unless all of these factors are considered, reasonable use cannot be properly determined. Currently, regional councils do not have the tools or information to evaluate reasonable use, taking all of these factors into account, so most use guidelines or rules-of-thumb.

As an example, ECan often assesses consent applications for 5 mm/d or less averaged over the proposed irrigation return interval as reasonable. An allocation expressed in this way is a peak rate based on typical ET rates, and is the main method currently used to establish reasonable use. There are no measures of the volume of water used over a season, no allowances for effective and efficient use and no allowance for risk and reliability. Yet, the key issue for farmers is the risk of not being able to maintain adequate soil moisture either through inefficient irrigation, insufficient system capacity, or due to unreliable water supplies.

Whether or not the information requested in consent application forms contributes to achieving efficient irrigation depends on how that information relates to what actually happens in the field. The general understanding of ECan staff is that if applicants provide information that meets ECan guidelines, irrigation will be reasonable and efficient. Applicants generally fill in the forms in a way that they believe to be correct at the time the application is made. The information given may be similar to what eventually happens in the field, but it can also be quite different. Often, water supply capacities are unknown at the time of application, and the decision about what kind of system to use is not often made until the water source is proven. In addition, the designers of the irrigation systems are not party to or have no record of the consent information. It is rare for peak takes to exceed consented takes, but depths applied and return intervals can differ substantially from the information originally supplied.

In reality, there is a significant amount of uncertainty involved. The information provided can *indicate* whether the amount of water requested is likely to be reasonable and used efficiently. Because of uncertainty and variability in the field, the current process can be used as a screening method, rather than a decision process of *"Yes, this will be efficient"*, or *"No, this will not be efficient"*.

Given the uncertainty of determining reasonable use based on current consent application information and the limited linkages between consent applications and field practices, the current practice is limited in its use.

To determine reasonable use including peak rates and seasonal use, computer simulation of irrigation demand using daily climatic records over as many years as possible is the preferred method. The simulation should incorporate all the factors listed above. Simulation work already carried out for other studies (e.g. LE, 2000), shows that peak rates are relatively constant for different soil types, rainfall catchments and crop types. However, seasonal water use varies significantly with soil types, crop types and rainfall areas.

Allocating water for a reasonable level of seasonal water use subject to a peak rate of take based on simulated demand would simplify consent evaluations, as it would remove the need for detailed system information.

7.5 Conditions

Consents are usually issued with conditions attached.

The conditions described in Section 6 – ECan Conditions 1(a), 1(b), 1(c) – could result in efficient use of water if they were able to be implemented and monitored, and if only crop ET was being considered. They would reduce or prevent adverse environmental effects only if they resulted in less water being taken from the source and if losses such as drainage to groundwater could not be beneficially used or if there was an adverse change in water quality due to drainage.

In practice, the conditions cannot be easily implemented and monitored by water users and cannot be practically monitored by ECan staff to ensure compliance.

ECan Conditions 2(a) and 2(b) – which refer to water metering – are reasonable, but on their own will not result in efficient use of water. Water meter readings need to be incorporated into an irrigation efficiency or water monitoring programme with follow-up to ensure best use is made of the measured data. Implementation of water meters is not technically difficult, but retrofitting to older systems will be more costly than fitting them to new systems.

Conditions that restrict water supply can encourage efficient use in some respects or discourage efficient use in others. Two examples of conditions discouraging efficient use are groundwater trigger levels (as currently used in West Melton) and flow restrictions on rivers (such as the Rakaia NCO).

In the case of groundwater, farmers who depend heavily on irrigation irrigate as much as possible if they think groundwater trigger levels are about to be reached. The logic is that it is better to go into restrictions with soil moisture fully restored to reduce the risk, and irrigation often takes place when it was not necessary. This may exacerbate the problem of low groundwater levels. The issue with groundwater restrictions is that once applied, they are not usually removed until the groundwater is recharged in the following winter, so farmers try to minimise their risk as much as possible.

In the case of the Rakaia River, surface irrigators almost always irrigate at the end of each month in spring/summer regardless of soil moisture conditions because the next month has higher minimum flows and in their view, higher likelihood of restrictions. Once again, farmers are trying to minimise the risk.

If restrictions are removed within the irrigation season, farmers can utilise higher system capacities (higher peak rates) if they have the extra capacity available to "catch up" as quickly as possible. In this case, peak rates that may appear to be unreasonable could be necessary to improve overall irrigation reliability and performance. Currently, very few irrigation systems have high "catch up" ability during the peak of the season.

7.6 Measuring and Monitoring

For the majority of irrigation efficiency, application efficiency or reasonable use definitions, a measure of water use forms part of the definition. Unless water use is measured, it is almost impossible to make any judgements about irrigation efficiency. Water managers who do not require water metering are always going to find it difficult to monitor efficient use.

Flow measurement is not routinely specified as requirements on consents in Canterbury. Even if water meters are specified, they need to be installed correctly, maintained in good working order, and need to be read. Experience in other regions shows that obtaining reliable water usage data from flow meters is not guaranteed, primarily because of lack of follow-up on supplying usage data to regional councils.

Requiring users to install water meters to obtain information on peak rates of take alone would be unlikely to be justified because peak take is not normally recorded by most meters – it requires short-term monitoring – and peak take information can be obtained in other ways. Where volumetric meter readings form part of a longer-term water allocation or water use monitoring programme, water meters are of significant benefit to water managers. In addition, they are extremely helpful to farmers in improving irrigation/production performance.

The requirement to measure soil moisture is not used as a consent condition in Canterbury and is only specified in a small number of consents in other regions. Yet, as with water use, monitoring soil moisture or at least carrying out water budgets is necessary if irrigation is going to be managed efficiently. Effective soil moisture measurement can also reduce the risk of both under-irrigating and over-irrigating.

The condition relating to not exceeding field capacity is virtually impossible to meet (especially with border-strip irrigation) and does not take into account the requirement to apply greater depths than the average deficit to overcome non-uniform applications for effective irrigation. In addition, it is virtually impossible to monitor. Other conditions such as fixing leaks are important visually but add little to the goal of achieving efficient irrigation.

If regulation is to be used, the outcomes must be clearly defined and able to be monitored. Defining irrigation efficiency in itself is difficult enough. It is impractical to accurately monitor application efficiency on a per irrigation basis. Soil moisture monitoring can certainly help to improve application efficiency, but cannot be recommended to routinely provide reliable values of application efficiency.

7.7 Irrigation as a Permitted Use

Currently, consent to take water for irrigation and to use water is combined. The quantity of water applied for is checked to ensure it is reasonable and assessments are carried out to determine the effect on the environment of taking and using the water. In the past, the emphasis has been on the take, but more recently the use of the water, particularly with respect to the effect on groundwater quality, has been included. The efficient use of the water has been partially addressed through consent conditions.

The concept of separating the take of water from the use of water has been proposed. There are advantages and disadvantages to separating take from use. The advantages are:

- Takes can be used for multiple purposes without applying for new consents or variations to existing consents because the use of the water is separated from the taking of water;
- Takes from multiple sources (e.g. scheme water and groundwater) can be used under one consent;
- Better allocation of water could be achieved, because duplicate allocation of water to single areas can be identified;
- It is possible to make the use of water a permitted activity under defined circumstances.

The disadvantages are:

- Significant additional administrative, processing and monitoring costs to consent applicants and holders;
- Users would be unable to irrigate under a current "scheme" consent. The scheme would hold a consent to take water, but individual farmers would require a consent to use that water.

Although the use of water for irrigation has many beneficial effects, it has the potential to be inefficiently used and over-applied, leading to adverse effects on receiving waters (such as groundwater, lakes and streams) through increased leaching of contaminants. For the use of water for irrigation to be a permitted activity, regulatory authorities would need to be reasonably certain that the activity would either not adversely affect receiving waters or, if it did, the effect would be within acceptable guidelines set out in a Plan.

It should be possible to develop a set of guidelines that, when followed, could provide a selection process for deciding whether use of the water would be likely to result in adverse effects.

Several factors need to be considered.

- The scale of the activity is important. Irrigation of large areas with high system capacities could adversely affect receiving waters much more than irrigation of small areas with low system capacities.
- Potential adverse effects could be acceptable or not acceptable, depending on the location of the activity and land use. Some activities may need to be discretionary in some areas but not in other areas.
- The standard of design and installation of the irrigation system is important. Poorly designed and installed systems have the potential to result in higher leaching than systems that are well designed and properly installed. The use of registered designers/installers for new systems and design audits of new and existing systems could ensure standards of design were acceptable.
- The standard of irrigation management is important. On-farm monitoring of water use and soil moisture improves the likelihood of efficient irrigation and minimal

adverse effects. Again, audits of system operation could ensure operation of the system was acceptable.

If a farmer met and agreed to follow a set of requirements for a permitted activity, a consent to use the water could be avoided. However, the administrative overhead of complying with the conditions may exceed that of obtaining a consent.

An example of a set of criteria for water to be a permitted use for irrigation could be:

- Size of irrigated area (e.g. <20 ha);
- Size of takes (e.g. <10 ℓ/s);
- Standard of design – registered designer/installer endorsed by NZIA;
- Can reach at least 80% application efficiency;
- System audit meeting required standard;
- Soil moisture monitoring perhaps;
- Seasonal summary of performance measures provided to ECan.

8 CONCLUSIONS

The study objectives were to define terms, to identify what is a reasonable/desirable level of irrigation application efficiency, and to review conditions of water use that:

- ECan can promote as policy in the NRRP. Application efficiency needs to be robustly founded (e.g. realistic in terms of systems that are available), reasonably achievable, and necessary for promoting sustainable management and good resource management.
- ECan can use in its reasonable use test assessment of how much water to allocate to an individual wanting a water permit for irrigation and when setting conditions for these water permits.
- ECan can defend as assisting in the fair allocation of the water resource with the least adverse environmental effect.

8.1 Definition of Terms

Fourteen definitions of efficiency have been described and evaluated under the headings of *irrigation efficiency*, *application efficiency* and *distribution efficiency*. The key findings are:

- There is no single definition that would necessarily result in efficient use of water, or reduce or prevent adverse environmental effects.
- Most of the definitions are impractical because they involve components that are difficult to measure or assess to an accuracy suitable for monitoring.
- Application efficiency definitions can give an indication of irrigation efficiency for individual applications but are unsuitable for assessing seasonal efficiency because they do not encompass the wider aspects of beneficial or reasonable use.
- Distribution efficiency definitions are more relevant to irrigation designers and not suitable for regular use by ECan staff.
- SIE, which can be reasonably easily calculated provided that water use is measured, will provide an indication of whether seasonal water use has been reasonable and efficient.

8.2 Appropriate Levels of Application Efficiency

- There are at least twenty different kinds of irrigation systems with many variations currently used in New Zealand. It is impractical to reliably specify achievable application efficiencies for each type individually.
- Most sprinkler and trickle systems have the ability to be operated at high application efficiency but this can compromise overall irrigation efficiency.
- Based on data from New Zealand and overseas, reasonably achievable application efficiencies for spray and trickle systems is 80%. The reasonable achievable application efficiencies for border-strip systems will range from 40-60%, depending on soil type.

- Irrigation efficiency is affected by the design of the irrigation system and how well it is managed. Good design provides the potential for efficient irrigation but does not guarantee it.

- The factors most affecting application efficiency are distribution uniformity and excessive application depths and rates.

8.3 Reasonable Use

- The method of assessment of reasonable use in current consent applications is inadequate as it is based on 'average' ET rates and does not properly address the factors that determine reasonable use.

- There is a lot of uncertainty in the determination of water holding capacity, allowable deficits and return interval. These should only be used as a guide to assess whether the proposed irrigation has the potential to be used efficiently.

8.4 Consent Conditions

- If they could be implemented, ECan consent Conditions 1(a) to 1(c) could result in efficient use of water when measured in terms of application efficiency. This could contribute to a reduction in adverse environmental effects. However, the gains in efficiency will be small.

- ECan Conditions 1(a) to 1(c) can be partially implemented by water users, but cannot be practically and realistically monitored by ECan to ensure compliance.

- ECan Conditions 2(a) and 2(b), with modification, will provide the means to improve irrigation efficiency through better allocation and monitoring. However, the way water is allocated and use is monitored will need to change to obtain the improvements.

- EW Condition (a), as written, is meaningless. However, the intention of the condition will achieve similar results to ECan Condition 1(a).

- EW Condition (b) is not likely to reduce or prevent adverse environmental effects, but could provide some control over them. Although a monitoring programme can be implemented, associating a change in nitrates with a specific property will be difficult.

9 RECOMMENDATIONS

For allocation of water for irrigation and for inclusion into a reasonable use test, the following definitions are recommended:

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

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

These definitions are not recommended for routine monitoring due to the difficulty in determining water stored in the crop root zone.

To allow the water to be used for uses in addition to replacing soil moisture deficits, a broader definition that allows for replacing soil water deficits, and other needs such as germination, cooling, frost protection, leaching and pest control, is recommended. The definition defined by Burt *et al.* (1997) is preferred:

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

For allocation of water and for determining reasonable use, an application efficiency (definition 11) of 80% is recommended for all spray and trickle systems.

For surface irrigation systems in water-short areas where losses to drainage do not have a beneficial use, an application efficiency of 80% is recommended.

For border-strip systems where losses to drainage have a quantifiable beneficial use, where there are no adverse effects and where water supply is not limited, application efficiencies of 50% are recommended.

The current reasonable use test is inadequate and needs to incorporate other factors pertaining to both peak system capacity and to seasonal water use if minimal adverse effects on source and receiving waters are to be achieved. Appropriate limits can be best achieved by updating current guidelines using computer simulation or by development and use of a more comprehensive decision support system.

Monitoring of irrigation application efficiency is extremely difficult to do for each irrigation application. Monitoring of reasonable use can be better achieved by implementing water metering and use of an alternative definition, as follows:

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

A range of expected values can be developed for this definition. With water metering, values actually achieved can be calculated.

Consent conditions relating to reasonable and efficient use should include:

- Peak rate of take (measured in ℓ/s or equivalent) at a frequency appropriate to the use of the data;
- Seasonal volumes of water allowed to be taken, based on reasonable use;
- A requirement to submit volume of water used each season.

Water allocation based on reasonable use, and consent monitoring to ensure conditions relating to pumping rates and volumes of water abstracted are met, should be the primary means of encouraging efficient irrigation. Other ways where Ecan can contribute are as follows:

- Support initiatives to increase reliability of water supply;
- Support implemention of irrigation design standards and audits;
- Educate farmers in good irrigation practice such as using soil moisture monitoring;
- Educate irrigation system providers and managers in good practice;
- Make greater use of water user groups;
- Promote the use of performance indicators.

Because detailed monitoring of field practices is impractical, water use should be metered as a means of assessing seasonal use. It will be necessary to monitor water actually used and re-evaluate use to find out if the process is working. Where restrictions are imposed, they should be made on a volumetric basis as early in the irrigation season as possible. This will encourage efficient use.

The most practical options for assessing irrigation efficiency are irrigation design audits and calculation of performance indicators. Irrigation audits are a good way of checking adequacy of consents and identifying design and operational problems. Performance indicators are useful for assessing whether irrigation performance is improving or deteriorating over time.

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