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Investigating Dairy Farm Irrigation Efficiency in the Reporoa Basin

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TABLE OF CONTENTS

Page

List of Tables

List of Figures

List of Appendices

List of Acronyms

EW	Environment Waikato
LE	Lincoln Environmental
LVL	Lincoln Ventures Ltd
TRC	Taranaki Regional Council

List of Abbreviations

awc	available waterholding capacity
CSMM	conceptual soil moisture model
CU	coefficient of uniformity
DU_{lq}	distribution uniformity lower quartile
ha	hectares
l/s	litre per second
kgDM/ha	kilograms of dry matter per hectare
kgDM/mm	kilograms of dry mater per millimetre
m	metre
m^3	cubic metre
m^3/d	cubic metre per day
MS	milk solids
NZLRIS	New Zealand Land Resource Information System
Paw	plant available water
PET	potential evapotranspiration
Praw	plant readily available water
Sn	standard deviation

Acknowledgements

The participating farmers entered into the project voluntarily and with enthusiasm. They willingly contributed, giving both their time and information. Their interest and involvement in the project demonstrates the importance of irrigation as a key tool to sustainable dairy farming in the Reporoa area.

Mark Blackwell - Dexcel; was consulted on the finding of pasture production studies in the Reporoa area, this information assisted with the formulation of the pasture production model.

Marie Gaukrodger - Trustpower; provided information on electricity consumption for the study farms as well as the charging structures for electricity supply in the south Waikato.

EXECUTIVE SUMMARY

This study forms part of Environment Waikato's (EW) on-going commitment to the sustainable management of water resources in the Waikato region. This commitment includes the investigation of practical, economic and social methods to improve water use. It follows on from earlier studies establishing crop water requirements, irrigation efficiencies in the Franklin area and a review of the resource consent process.

Irrigation is a major consumptive use within the region, much of which is allocated for irrigation of pasture on dairy farms. It has been widely adopted on dairy farms in the Reporoa basin of the south Waikato, as a means to achieving sustainable increases in farm production. The area is prone to summer drought due to a combination of lower rainfall and low waterholding pumice soils. Surface water resources have been allocated for irrigation from the Waikato River and tributary streams. There are at least 28 farms in the basin with a combined irrigated area of more than 2,500 ha and daily allocation in excess of 100,000 cubic metres per day (m^3/d).

Study Outline

The purpose of the study was to investigate current levels of irrigation efficiency on dairy farms and the costs and benefits of improvements in efficiency. It was based on a sample of 12 irrigated farms in the Reporoa basin. The sample included the range of commonly adopted irrigation methods, these were; centre pivot (3), K-lines (2), long-laterals (4) and travelling gun irrigators (3). The three farms with centre pivots also used other methods (K-line, long-lateral and travelling irrigators) to irrigate areas not covered by the pivot. The farms had combined effective and irrigated areas of 1,800 and 1,100 hectares respectively, and total water allocation equivalent to 55,180 m^3/d.

The study is based on a farm system approach, utilising a variety of data sources and analytical methods. A key element was the farm survey, which collected information on irrigation methods, cost and management as well as farm productivity. Other information sources included climate data (Reporoa, Rotorua and Taupo), soils data (waterholding characteristics), water use records and irrigation pump electricity consumption (for calculation of seasonal water use).

While there are a large number of definitions of efficiency associated with irrigation and water resource management, the most relevant to this study are;

- Application efficiency; the ratio of water retained within the crop rootzone to the total applied. It does not include water losses between the pump and application point (sprinkler) however for the range of pressure irrigation systems in the Waikato these are considered to be low. The analysis of efficiency, as listed below, was carried out for the farms based on an empirical evaluation of application efficiency (from system type and management) and for the season based on a water balance of irrigation demand and pumped volume.

- Water use efficiency; is the volume of water used compared to the crop productivity or returns (kg or $). It provides an indication of how efficiently water is used to produce farm output.

Farm Application Efficiency

The analysis of farm application efficiency is based on three key elements; the application uniformity (expressed as the coefficient of uniformity (CU)), system application efficiency (incorporating losses due to pressure variations and wind) and overall farms application efficiency (incorporating irrigation management elements).

The table below lists the results of the analysis, the main points to note are:

- CU values for the manual-move systems i.e. long-lateral, K-lines and travelling irrigators ranged from 50 to 67%. Key factors influencing uniformity, apart from sprinkler make and model, were; sprinkler spacing and location (between shifts) and wind. Centre pivot CU values were higher (85%) due to better pressure regulation and sprinkler selection.
- System application efficiency ranges between 75 to 90% with the higher values recorded for the centre pivots.
- Farm application efficiency exceeded 80% for all farms. These were higher than anticipated values, the principal reason appears to be that irrigated areas have been maximised on the farms, presumably to maximise the returns from the investment in irrigation.

Farm No.	System(s)	System Efficiency		Farm AE (%)
		CU (%)	AE (%)	
1	Long-lateral	57	79	82
2	Long-lateral	62	81	>100
3	Long-lateral	62	81	80
4	Long-lateral	67	84	>100
5	K-lines	50	75	>100
6	K-lines	63	82	>100
7	Centre-pivots (1)	85	90	96
8	Centre-pivots (2)	85	90	86
9	Centre-pivot (3)	85	90	>100
10	Travelling gun	60	80	>100
11	Travelling gun	60	80	>100
12	Travelling gun	55	78	>100

Notes: Other systems on farms with centre pivots included; (1) K-lines and fixed sprinklers, (2) long-lateral and (3) travelling gun irrigators

Seasonal Application Efficiencies

As indicated above the analysis of seasonal application efficiency was based on the evaluation of irrigation demand (from soil water balance modeling) and pumped volumes. Pumped volume was assessed from water meter records (where available) and electricity consumption. However, there were constraints to this analysis, due to the accuracy and continuity of records.

The results indicated high efficiency levels, which exceeded more than 80% (with the exception of one farm). The overall result is consistent with the analysis of farm application efficiency above, indicating a general trend of under-irrigation on many farms. This is contrary to the common perception that pasture irrigation is inefficient. Under-irrigation may be occurring for a variety of reasons, such as labour constraints, high operating costs, maximisation of irrigation investment and limitations of irrigation management (scheduling). It is likely to impact on pasture and farm productivity, with implications for feed and farm management.

Improving Irrigation Performance

While application efficiency was higher than anticipated, there is nevertheless room to improve irrigation performance. Improvements are likely to yield benefits in terms of pasture and farm production and returns.

Key factors to improving efficiency are:
- Long-lateral sprinkler location: efficiency is dependent on operator skill in correctly placing sprinklers to achieve high uniformity.
- K-line performance: on one farm the existing system requires revamping to improve flow rate and uniformity.
- Centre pivot uniformity: future work should look at direct measure of uniformity, to confirm assumed CU values.
- Wind affects: current information on wind speed in the Reporoa area is inconsistent (much lower) with sites in Taupo and Rotorua, and requires further evaluation, to assess the impact on sprinkler performance and irrigation management.
- Irrigation scheduling: irrigation management on farms in the area is solely based on local experience, this could be complemented with information on soil moisture levels, to improve efficiency particular on the shoulders of the season.
- Pressure variations; the adoption of pressure regulation and/or variable speed control for pumps, would improve system uniformity and efficiency, as well as reduce operating costs.

Productivity and Returns

The study evaluated the costs and benefits of irrigation. The key findings were:

- Capital costs ranged from about $2,500/ha for K-lines and long-laterals up to $4,500/ha for centre pivots.
- Labour requirements varied between systems, with typical inputs of 3 to 4 hours per day for manual move systems such as long-laterals.
- The pasture production benefits of irrigation were on average 4,000 kg of dry matter per hectare per year.
- Based on a milk solids payout of $3.70 per kilogram the net benefit of irrigation in the Reporoa basin is within the range of $330 to $450 per hectare. Based on annual irrigation demand this is the equivalent of 9 to 13 cents per cubic metre of irrigation water.
- Irrigation efficiency improvements could yield financial benefits in the order of $100 per hectare.
- Identified improvements are; improved application uniformity (sprinkler location, reduced operation during high wind and reducing pressure variations) and improved irrigation scheduling.

Recommendations

The study recommendations are:

i) Water use records: current procedures and process for recording water use be updated to improve the accuracy and continuity of records. The records should form a reliable data source for the evaluation of consent compliance and catchment water use. Options for improvement include use of dataloggers for large and non-compliant consent holders, and weekly recording on low volume consents.

ii) Seasonal water use: the current consent process is primarily focused on preservation of surface water flows. Consideration should be given to the development of seasonal allocations based on irrigation demand that incorporates rainfall and PET elements. This may ultimately include allocations incorporating annual volume components.

iii) Application efficiencies; the results for farm and seasonal application efficiency are both surprising and encouraging. But these results are based on an empirical approach, and on a number of assumptions on system design and management. These findings could be further refined, with an evaluation of application under field operation conditions. An on-farm irrigation audit methodology is currently being developed (a Sustainable Farming Fund project based in Hawkes Bay), which incorporates use of catch-cans for measurement precipitation rates. The next stage in the assessment of on-farm efficiency factors should consider the application of the audit methodology.

iv) Irrigation management; on-farm irrigation scheduling practices should be promoted to encourage water use productivity and efficiency. Current on-farm practices could be improved with the establishment of a local network, incorporating representative monitored sites (climate and soil moisture) to provide irrigators with a quantitative assessment of irrigation demand. There is an existing 'informal' irrigation group in the district, which meets regularly through the irrigation season. This group may be interested in formulating a project to establishing a local irrigation network. There are potential funding sources for such a project, such as the Sustainable Farming Fund, with contributions from EW, district councils and producer organisations.

v) Performance standards; current water resource consent allocations are based upon an assumed application uniformity (CU of 70%) and application efficiency (AE of 85%). However, there are no explicit performance standards specified for system design or management. The specification of irrigation performance standards as a resource condition, for example CU and DU for system type, would ensure systems are designed to meet minimum uniformity and efficiency levels. It would also establish a measurable benchmark for system assessment.

1 INTRODUCTION

This report presents the findings of a short-term study investigating water use efficiency in the Reporoa basin in the south Waikato. It was commissioned by Environment Waikato (EW) as part of its on-going commitment to the refinement and development of water resource management processes in the region. It follows on from previously commissioned work that established crop water requirements and evaluated water allocations, as discussed below.

Environment Waikato has identified the investigation of practical, economic and social methods to improve water use as a key issue in the current annual plan. This is consistent with the responsibilities of EW, under the RMA, for the sustainable management of water resources and the development of allocation methods.

Irrigation is a major consumptive allocation of water within the Waikato region. Much of this allocation is for the irrigation of pasture on dairy farms. On the pumice soils of the south Waikato with low water-holding capacity, irrigation has been widely adopted to maintain pasture production and reduce the financial risks associated with summer droughts. In the Reporoa basin there are now 28 dairy farms with a combined irrigated area of about 2,500 hectares and water allocation of more than 100,000 cubic metres per day (m^3/d).

This study investigated current levels of efficiency and productivity of water use on a sample of dairy farms (12) within the Reporoa basin. The sample included a range of commonly used irrigation methods; centre pivot, K-lines, long-lateral and travelling gun irrigators. The study was based on analysis of efficiency and productivity using analytical methods for readily available data, such as climate, pasture production, irrigation system specifications, electricity consumption and water use records. The approach to this analysis was pragmatic and had to assume a number of 'reasonable' conditions and assumptions. The objective of this analysis was to assess current efficiency levels, identification of key factors to improving efficiency and the associated financial costs and benefits of such improvements.

1.1 Related Work

There have been a number of related studies investigating water use efficiency and productivity for irrigation of pasture within the region and New Zealand. These include:

- Crop Water Requirements for Irrigation in the Waikato Region (Landcare, 1997); the study was commissioned by EW to establish irrigation requirements for crops and pasture in the Waikato. It used a soil water balance model to determine water requirements for the major crop types and climate zones within the region. The study classified the region into nine irrigation zones based on climate and soil types, for which it determined irrigation water requirements for pasture.

  The Reporoa area falls within zone five of the study, which includes an extensive area southeast of a line between Putaruru to Taumarunui. Two pumice soil types were identified within the zone, Taupo and Kaingaroa, with available water-holding capacities (AWC) within the pasture rooting depth (50cm), of 127 and 157 mm respectively. However, the study notes that "*although the pumice soils have apparently good water storage on the basis of laboratory tests, field experience indicates otherwise*", therefore, AWC values of 40 and 80mm were assumed for the determination of irrigation requirements. The soil water balance was based on rainfall and potential evapotranspiration (PET) records for Taupo (average rainfall of 1,200 mm) and Rotorua respectively.

The determination of irrigation requirements was based on two criteria: (1) maintaining a soil water level above an absolute minimum of 25% of AWC during the month of greatest demand (January) and (2) soil water levels greater than 50% of AWC for 90% of the time. These criteria were adopted as a reasonable basis for economic system design and operation. As indicated in Table 1 daily water requirements were estimated at 57 m^3/ha/d for both soil types. Application depth and return intervals varied between the soil types, from 17 mm per 3 days and 40 mm per 7 days for Taupo and Kaingarao pumice respectively.

Table 1: Water requirements for pasture in Waikato (after Landcare, 1997)

		Taupo pumice	Kaingaroa pumice
Available water capacity (mm)		40	80
Applied water (mm)		17	40
Return interval (days)		3	7
Annual water requirements	(50%ile)	552	413
	(90%ile)	664	530
Average irrigation days per year	(50%ile)	32	10
	(90%ile)	39	13
Daily water requirements (m^3/ha/d)		57	57

- Investigation of Efficiency of Water Allocation and Use (Rout, 2002); the study was commissioned by EW to investigate efficiency of irrigation methods in the Pukekohe area and evaluate resource consent in the wider Waikato region. The study found considerable variations in application efficiency between irrigation systems due to variations in system type and operating conditions. Recommendations for improving efficiency included better pressure regulation, lower application rates for gun irrigators, lower application depths per irrigation event and shorter return intervals.

  The assessment of resource consents showed that allocations were often not well matched to predicted crop water requirements. In some cases actual water use was less than allocation, indicating that the resource was being under utilised. The study recommended improvements in the allocation mechanism to match allocation and demand, better verification of take rates and improved monitoring of water use.

- Optimisation of Farm Irrigation (Rout, 2003); the Taranaki Regional Council commissioned the study to investigate and classify irrigation development potential in the Taranaki region. The study evaluated the potential for irrigation development in the region based on irrigation demand, pasture production and financial benefits. Eight irrigation zones were identified within the region. In the zone of highest demand, around Inaha in south Taranaki, irrigation contributed on average an additional 4,400 kgDM/ha with a marginal benefit of more than $230/ha.

2 PROJECT DESCRIPTION

This section presents a brief summary of the study including objectives, location, farm selection criteria, general approach and outline of report sections.

2.1 Objectives

The principal objectives are:

i) To determine water use efficiency and identify improvement to dairy farm irrigation systems, with the specific objectives of:
- Evaluation of irrigation system efficiencies
- Evaluation of seasonal water use efficiencies
- Identification of improvements in irrigation methods and management to increase water use efficiency

ii) To evaluate the financial costs and benefits of improvements in irrigation efficiency, with the specific objectives of:
- Evaluation of costs of irrigation – capital and operating
- Evaluation of production and financial benefits of irrigation
- Evaluation of financial benefits of improved water use efficiency

2.2 Study Area

The study area is centred on the Reporoa basin of southern Waikato, as shown in Figure 1. Land use, rather than distinct geographical or hydrological boundaries, largely define the area of interest. The two main land uses within the basin are dairy farming and forestry. Soils within the area are predominately of volcanic ash origins, characterised as free draining and of low water-holding capacity, prone to summer droughts.

While dairy farming has been practised in the area for more than 30 years, since the late 1980s, there has been a trend toward irrigated pasture production to reduce the risk and impact of summer droughts. There are at least 28 irrigated farms within the area, with a combined consented daily take of more than 103,000 cubic metres per day (m^3/d) and cumulative take rate of 1,820 litres per second (l/s). Based on a peak daily water demand of 40 cubic metres per hectare (m^3/ha) these farms are estimated to have an irrigated area of around 2,500 hectares[1].

Almost all of this water is abstracted from surface water sources, either from the Waikato River or its tributaries. Figure 2 shows the location of current resource consents within the study area.

[1] Note this is lower than the peak allocation rates, but is based on the actual rate recorded for the case study farms (Section 2.3)

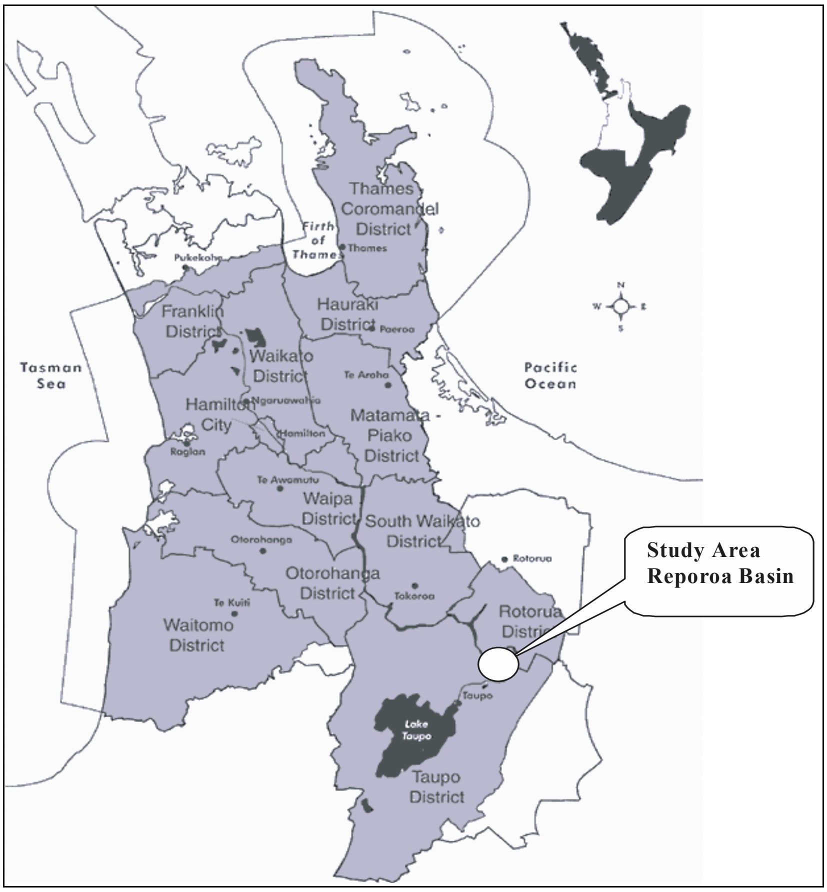

Figure 1 Study Area

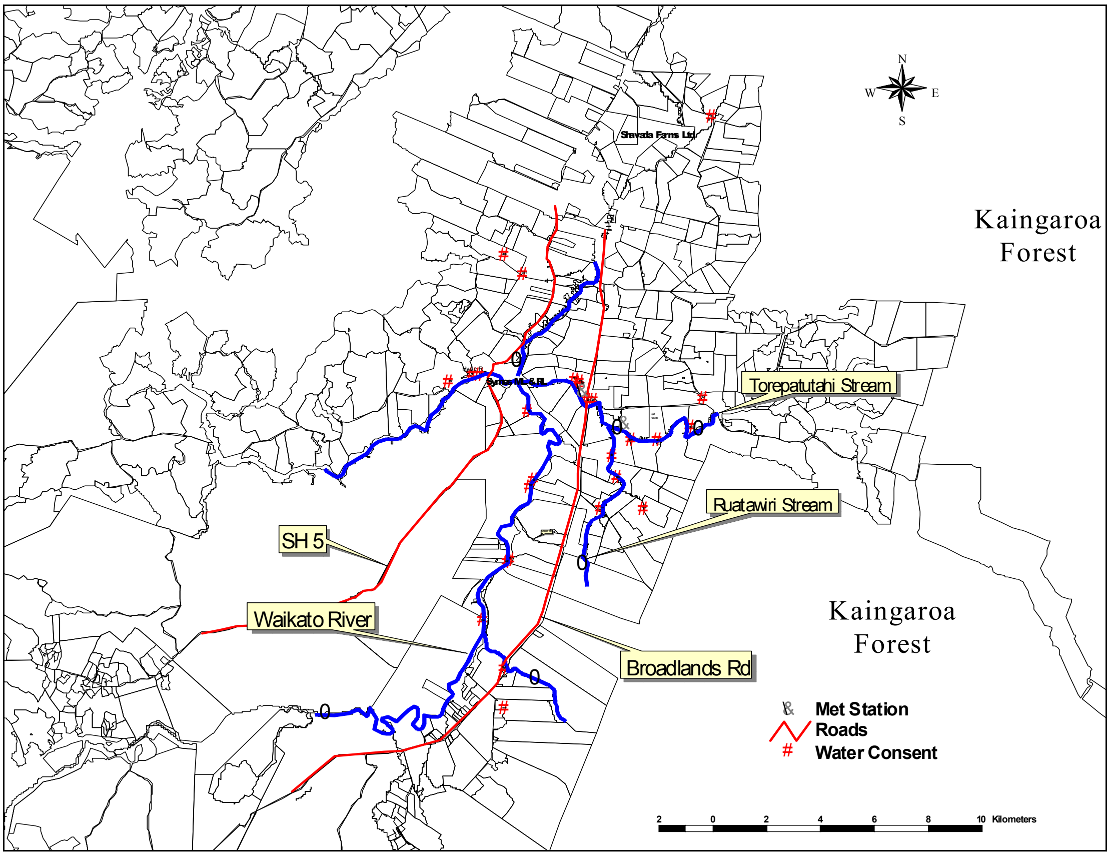

Figure 2 Location of water consents in Reporoa area

2.3 Farm Selection

The study is based on a sample of 'case' farms within the study area. The criterion for selection of these farms were:

- Irrigation method; EW records indicated that four irrigation methods were adopted by farms in the area; long lateral (Bosch), K-lines, travelling gun irrigators and centre pivot, therefore the sample included examples of all four methods.
- Water use records; the existence of a 'reasonable' time-series of water use records was a pre-requisite for farm selection as these records form the basis for analysis of farm water use efficiency. However, as indicated in Section 3.2.2, water use records for many farms were incomplete or of short duration.
- Co-operation of farm owner; the preliminary group of selected farms were contacted by phone to outline the project and to confirm willingness to participate. All farmers were sent by fax or Email an outline of the project and summary of requested information in preparation for an on-farm meeting.

A total of twelve farms were selected for the study. Table 2 presents a summary of the farms including owner, irrigation method, areas and current water allocations. The twelve farms have a combined property area of nearly 2,000 ha of which about 1,800 and 1,100 hectares of effective and irrigated areas respectively. They represent more than 45% of the total irrigated area in the Reporoa basin. The farms have a total water allocation of over 55,000 m^3/d at combined take rate of 861 l/s (about 50% for the current allocation in the area).

Irrigation systems on the farms included:

- Long-lateral (4) (often referred to as 'Bosch' long-lateral); the application method is a single impact sprinkler with wetted diameter of 30-35 m, which is moved by motorbike around the paddock typically on a nominal five or six day rotation.
- K-line (2) (or Easi-rain); the application method is a series of impact sprinklers (wetted diameter (25-30 m)) mounted within a 'pod' and along a movable lateral. The lateral is rotated around the paddock by towing (by motorbike or car) on return interval of 6-8 days.
- Centre pivot (3); long self-propelled lateral boom on which sprinklers are mounted that rotates around central pivot point. On the study farms, various other methods (K-line, fixed sprinklers, and travelling guns) were used to irrigate areas not covered by the pivot.
- Travelling gun irrigator; comprised of large gun irrigator and hard hose reel, the guns typically had wetted width of 50-80 m and run lengths of up to 300m.

Summaries of information for the study farms is presented in Appendix A, including water resource consents, farm and irrigated areas, irrigation specific capacity and application depth and irrigation methods.

Table 2: Summary of Case Farms

Fm No	Irrigation Method(s)	Areas (ha)			Allocation	
		Total	Effective	Irrigated	m3/d	l/s
1	Long-lateral	78	75	75	4,560	87
2	Long-lateral	141	132	82	3,750	87
3	Long-lateral	173	169	114	8,500	170
4	Long-lateral	133	125	125	6,250	78
5	K-line	104	100	100	4,030	93
6	K-line	62	60	60	3,000	13.8
7	Pivots, K-line, Sprinkler(3)	400	375	189	8,640	100
8	Pivot, Long-lateral	87	75	64	4,320	72
9	Pivot, Travelling Guns	470	370	140	6,700	83
10	Travelling Gun	126	126	24	1,350	17
11	Travelling Gun	82	74	40	1,380	22
12	Travelling Gun	94	92	74	2,700	38(4)
	Total	**1,950**	**1,775**	**1,087**	**55,180**	**861**

Notes (1): Utilizes a combination of 3 consents, (2) Van der Bijl second property, (3) Fixed sprinkler system for unirrigated pivot corner, (4) Estimated take rate.

2.4 Approach

The study is based on a farm system approach, utilising a variety of data sources and analytical methods including:

- Farm survey; the survey of case farms was conducted by interview and farm inspections, carried out over a series of visits to the study area in Feb-Mar. 2003. The survey was preceded by phone contact with the farm owners to discuss the objectives of the project. The survey results were recorded on a field form, listing general and specific information, including:
    - Irrigation system design - irrigation system layout and equipment specifications.
    - Irrigation management - irrigation duration and return intervals
    - Irrigation costs - capital and operating.
    - Milk solids production - total milk solid production for the current and preceding three seasons
    - Feed budget - information of on and off farm feed inputs including silage, concentrates and nitrogen fertiliser inputs.

- Climate data - EW has maintained a climate station on a property near Reporoa since 1998. The station records rainfall, soil moisture levels and parameters for the calculation of potential evapotranspiration. Additional rainfall and PET data was obtained for sites at Rotorua, Taupo and Sylvan Lodge (also located near Reporoa).
- Soils data; soil water-holding capacity, rooting depth and drainage characteristics were derived from the National Land Resource Inventory (Newsome et al, 2000).
- Water use records; EW provided information on water use for the farms based on submitted records from consent holders. These records varied in duration from several months to years, and in frequency of reading from daily to monthly. The water use records formed one of the elements for determination of farm water use efficiency.
- Water balance model; daily and seasonal irrigation demand was assessed using the Conceptual Soil Moisture Model (CSMM), a soil water model developed by LE. Inputs to the model are daily rainfall and potential evapotranspiration, crop type and soil type, and outputs include soil water content and irrigation depth. Appendix B presents a description of CSMM.
- Electricity consumption; with the consent of the farm owners the local electricity supply company (Trustpower) was requested to provide a summary of monthly electricity consumption for irrigation pumps on the study farms. Records were readily available for eight of the twelve farms for one or more irrigation seasons.

2.5 Report Outline

The report results and findings are presented in the following sections. These include:

- Section 3.0: Irrigation Efficiency; presents definitions of efficiency adopted in this study, analysis of irrigation efficiencies (system and seasonal) and key factors to improving irrigation efficiency on the study farms;
- Section 4.0: Financial Cost and Benefits of Improved Irrigation Efficiency; presents a summary of irrigation costs and benefits (productive and financial) and the analysis of the financial benefits of improving irrigation efficiency, and;
- Section 5.0: Recommendations; lists a series of recommendations for improving irrigation and water use efficiency in the Reporoa area.

3 IRRIGATION EFFICIENCY

This section addresses the issues associated with the first study objective that is the evaluation of irrigation efficiency. It presents a summary of the measures and definitions of irrigation efficiency adopted and their relevance to water use and resource management. It outlines the study and analytical methods. The findings of this analysis are presented in the final two sections on farm and season application efficiency. The approach to the presentation of methods and result is to keep the main body of the text concise and to provide supporting information in the accompanying appendices.

3.1 Definitions of Efficiency

Efficiency of water use is one of the key objectives of the RMA and therefore responsibility of the administrative authorities such as Environment Waikato. However, what is often not clearly defined in discussion of efficiency is what is meant by the term. As presented in a previous report on irrigation efficiency in the Waikato, there are a variety and range of definitions of irrigation efficiency (Rout, 2002). The relevance of a particular definition is dependent on the hydrological boundary and timeframe. One of the objectives of the resource management process, in terms of resource efficiency, is to optimise allocation to meet 'reasonable' demand. Reasonable demand was determined in the previous irrigation demand study (Landcare, 1997) based on crop water demand and acceptable levels of system performance, as discussed in Section 1.1.

Irrigation systems in the Waikato region are mostly discrete farm based systems, usually supplied from surface water sources. Likewise water allocations are based on individual consent holders for these systems. Therefore the farm is the most appropriate boundary for analysis of efficiency. Various timeframes can be adopted for measurement of efficiency, from individual events through to seasonal use that takes into consideration the impact of rainfall. Two timeframes have been considered in this study, the individual event as the basis for analysis of farm application efficiency (Section 3.3) and seasonal application efficiency (Section 3.4).

The following subsections present the measures and indicators of system performance and efficiency adopted in this study.

3.1.1 Application Efficiency

The application efficiency is the ratio of stored water within the crop rootzone to the total water applied to the soil. It does not include water losses between the pump and application point, however for the range of pressure irrigation systems in the Waikato these are considered to be low.

$$Application\,efficiency = \frac{Water\,stored\,in\,crop\,rootzone}{Total\,water\,applied} \qquad \text{Equation 1}$$

In the analysis presented in this report the total water applied is assumed to be equal to the total pumped volume, based on the assumption that conveyance losses are an insignificant proportion of the total volume. Water stored in the crop rootzone is estimated from a water balance model of irrigation demand. Total water applied is estimate from system performance and management for estimates of farm application efficiency (Section 3.3) and from water use or correlated from electricity consumption for seasonal application efficiency (Section 3.4).

The principal factors influencing application efficiency are:

- **System Design**: The two principal design factors that influence system efficiency are:

  i) **Application uniformity**; this is the evenness of application within the wetted area. For sprinkler systems it is a characteristic of the sprinkler type, spacing between sprinklers, operating pressure and wind. It is commonly measured as coefficient of uniformity (CU) or distribution uniformity (DU) as listed below:

$$\textit{Coefficient of uniformity}\,(CU) = 100\left[1 - \frac{\Sigma|x - \bar{x}|}{\Sigma x}\right] \qquad \text{Equation 2}$$

  Where:

  x = depth of water equal spacings across field
  $\bar{x}$ = average depth applied
  Σ = sum of all measured depths

  The coefficient of uniformity is a measure of the variability of the application depth from the mean. The smaller the average absolute deviation from the mean the higher the CU value. A value of CU = 100 percent means that irrigation is completely uniform. Under field conditions CU values for field sprinkler systems are typically in the order of 70 to 80%, but for some centre pivot systems can be more than 85%.

$$\textit{Distribution uniformity}\,(DU) = \frac{x_{lq}}{\bar{x}} \qquad \text{Equation 3}$$

  Where:

  x_{lq} = average depth applied of lower quartile
  $\bar{x}$ = average depth applied

  The distribution uniformity is a measure of how uniformly water is distributed within the lower quartile of the wetted area. The lower the mean application in the lower quartile the lower the DU value. In system design typically DU values of greater than 70% are recommended.

  ii) **Irrigation rate**; instantaneous application rate in excess of soil infiltration rates can lead to surface ponding and run-off. This is particularly relevant to gun irrigators with high application rates on the perimeter of the wetted radius. Soil types within the study area have high infiltration rates and the topography is to flat to undulating, therefore application rates are likely to be within acceptable limits.

- **System Management**: Inefficiencies arise out of system operation and maintenance factors, including:
  - Return interval – intervals too long or too short can result in under or over irrigation. Intervals shorter than required increase drainage losses.
  - Application depth – application of depths greater than the soil moisture depletion (within the root zone) increase drainage losses.
  - Operating pressures – operation of the outlets (sprinklers) outside the design pressure decreases application uniformity and increase losses.
  - Operating conditions – operating under adverse climatic conditions, such as high wind, reduces application uniformity and increases evaporative and drainage losses.
  - System maintenance – poor system maintenance can increase distribution losses in pipelines and decrease application uniformity.

3.1.2 Water Use Efficiency

Water use efficiency, that is the volume or depth of water used compared to crop production, gives an indication of how efficiently water is used to produce farm output. It is used in the latter section of this report to describe the contribution of irrigation to improved pasture and milk solids production.

$$Water\ use\ efficiency = \frac{Production\,(kg/ha)}{Water\ use\,(mm\ \ or\,m^3/ha)} \qquad \text{Equation 4}$$

3.1.3 System Capacity

The system capacity is commonly used as a benchmark to compare system performance to irrigation demand or water resource allocation. It is expressed as litres per second per irrigated area (l/s/ha).

$$System\ capacity = \frac{Irrigation\ system\ flow\,(\ell/s)}{Irrigated\ area\ (ha)} \qquad \text{Equation 5}$$

A comparison of actual system specific capacity with allocated specific capacity (i.e. allocated take rate (equivalent rate per 24 hours) over irrigated area) provides a useful indicator of how well matched the system is to the resource consent, and the potential for over or under irrigation.

3.2 Study Methods

3.2.1 Farm Application Efficiency

The evaluation of the application efficiency of the farm irrigation systems for the case farms is based on the following methods and assumptions:

(a) Assessment of system CU based on system type including:

- System type - distinction is made between the irrigation methods i.e. centre pivot, movable laterals (long, K-line and Easi-rain), fixed sprinkler and travelling gun.
- Sprinkler make and model - where available, distribution uniformity information was utilised to assess distribution uniformity, this included information obtained for Naan and Nelson sprinklers.
- Sprinkler spacing(s) - between and within sprinkler rows and for movable systems were based on assumed overlap patterns as discussed in Appendix J.
- Operating pressure - either from recorded operating pressures or assessed operating pressures for system pump type and rating, and taking into consideration pressure variation due to fiction losses and elevation.
- Wind - assessment of the potential impact on distribution.

(b) Irrigation management based on:

- Irrigation demand - irrigation requirements for pasture was based on soil water balance for the period 1998-2002. This assessment was made using a soil water balance model (Conceptual Soil Moisture Model (CMSS)), as discussed below.
- Return interval - either reported return interval or as per design specification for the system type. Movable lateral systems such as K-lines and long-lateral are designed for a nominal return interval, typically 6 days.
- Application depth - calculated as the mean application depth for the sprinkler type, spacing, flow rate and irrigation duration.

3.2.2 Seasonal Application Efficiency

The seasonal application efficiency is assessed for the farms based on a comparison of calculated irrigation demand and estimated water use. Irrigation demand was calculated with the Conceptual Soil Moisture Model (CMSS) as discussed in Appendix B. Inputs to the model include daily climate data (rainfall and potential evapotranspiration), crop type, soil water-holding capacity and irrigation management schedule.

For the analysis of irrigation demand presented in this report, the CMSS inputs were:

- A compilation of daily rainfall and PET data from two sites in the Reporoa area; the EW Reporoa site (rainfall and PET) and Sylvan Lodge on Broadlands Road (rainfall). Initial analysis indicated that PET data for the EW site was considerably (20%) lower than data for Rotorua, as indicated in Appendix D. While some variability can be expected due to local effects, the consistently lower values for Reporoa appear to be due in part to significantly lower wind speeds. The Reporoa PET values appear to be abnormally low, therefore a correction factor of 20% was adopted for the analysis of irrigation demand.
- Soil water-holding capacity was derived from the New Zealand Land Resource Information System (NZLRIS) (Newsome et al, 2000). The NZLRIS provides information the Plant Readily Available Water (Praw), which is estimated from the volumetric water content difference between -

10 kPa to -1500 kPa in the 0-0.4 m layer(s) and between -10 kPa to -100 kPa in lower layers (Webb et al, 1995). Appendix C lists a summary of soil waterholding characteristics for the case study farms (Praw and Paw), which were similar for all farms. For the purposes of evaluation of irrigation demand a Praw value of 75 mm was adopted. It should be noted that this is higher than the arbitrary value of 40 mm adopted in the previous study of crop water requirements (Landcare, 1997). This higher value appears to be consistent with field observation, based on current irrigation practices within the Reporoa area, i.e. application depths of 30 - 40 mm on 6-8 day return interval appear to be maintaining good pasture production without excessive water stress.

- The crop type assumed in the CSMM is grass with an effective rooting depth of 50 cm, the same depth as adopted in previous studies (Landcare, 1997).
- As outlined in Appendix B a variety of irrigation scheduling regimes can be used in the CSMM. For the purposes for the evaluation of irrigation demand, the irrigation schedule was based on fixed depth application (36 mm or 50% of Praw) on a fixed return interval (6 days) (as shown in Appendix G).

The assessment of estimated water use was based on a combination of:

- Water use records; EW provided currently available records for the farms. There was considerable variation in quality and quantity of records, in some cases no records were available, while on other farms duration of records varied from a few months to several seasons.
- Electricity consumption; to supplement the limited water use records, monthly electricity consumption records was analysed over the period 1998-2002. Water use was estimated based on pump motor rating (kW) and monthly consumption. While this is a less accurate estimate of water use than water meter readings, it nevertheless can be within reasonable limits and for some farms provides a more complete assessment of seasonal use than the existing water meter records.

3.3 Farm Application Efficiency

The assessment of farm application efficiency is based on an empirical evaluation of system performance. It represents the potential upper limit of system efficiency during periods of peak water demand and with the system operating within the consented water allocation.

As indicated above this evaluation is dependent on two principal elements, system application uniformity and irrigation management. The system uniformity is measured as the coefficient of uniformity (CU) and represents the variability of application within the irrigated area. As outlined in Appendix J the CU for the irrigation systems was derived from a variety of sources, for long-laterals and K-lines it is determined from sprinkler spacing and distribution uniformity, while for centre pivot and travelling gun irrigators it is derived from published information on system performances. It also took into consideration the impact of variations in operating pressure and the potential affects of wind. The key management components in the assessment of application uniformity are irrigation demand, return interval and application depth.

The CU of long-lateral systems is a largely a function of the sprinkler spacing. The systems are designed on the principle of matching wetted area (i.e. sprinkler wetted area times return interval) to paddock area. An acceptable level of sprinkler overlap (approximately 40-60 %) is achieved from the second irrigation cycle onwards. For K-lines spacing between sprinklers and lateral location remain relatively constant between cycles, therefore CU is a function of sprinkler type, operating pressure and spacing.

Table 3 shows the summary of the coefficient of uniformity and application efficiency (system and farm) for the study farms. The CU of the systems ranged from 60 to 90%, but generally with the long-lateral, K-lines and travelling gun irrigators in the range of 70-75% and centre pivots at 85%.

The farm application efficiency in Table 3, is weighted on an area basis (per irrigation method) for the farm as a whole. Values for all systems were generally high, at close to 80%. Values greater than 100% indicate that during period of peak demand, application efficiency is likely to be high due to either constraints on system design, management or water allocation. Management constraints may be due to; long return interval and/or low application depths. The constraints on water allocation may be associated with allocations lower than required to meet peak demand.

Table 3: Summary of Application Uniformity and Application Efficiency

Farm No.	System(s)	System Efficiency		Farm AE (%)
		CU (%)	AE (%)	
1	Long-lateral	57	79	82
2	Long-lateral	62	81	>100
3	Long-lateral	62	81	80
4	Long-lateral	67	84	>100
5	K-lines	50	75	>100
6	K-lines	63	82	>100
7	Centre-pivots	85	90	96
"	Easi-rain	57	79	
"	Fixed Sprinkler	55	78	
8	Centre-pivots	85	90	86
"	Long-lateral	60	80	
9	Centre-pivot	85	90	>100
"	Travelling gun	55	78	
10	Travelling gun	60	80	>100
11	Travelling gun	60	80	>100
12	Travelling gun	55	78	>100

The analysis shows that on most farms high application efficiency is likely to occur during periods of prolonged peak demand. This is largely due to allocation being closely matched to irrigation demand, a point illustrated by the system capacities for the farms as shown in Table 4. The table shows the system capacity based on daily allocation (m^3/d) and irrigated area (ha), which range from 0.4 to more than 0.8 l/s/ha, but with most farms around 0.55 to 0.65 l/s/ha. The analysis of irrigation demand shows that a system capacity of about 0.57 l/s/ha is required to meet irrigation demand (at an assumed CU of 70% and AE of 85%).

Table 4: System capacities for study farms

Farm No.	Irrigation Method(s)	System Capacity l/s/ha	Farm Efficiency (%)
1	Long-lateral	0.704	82
2	Long-lateral	0.529	>100
3	Long-lateral	0.863	80
4	Long-lateral	0.579	>100
5	K-line	0.466	>100
6	K-line	0.579	>100
7	Pivot(2), K-line, Sprinkler	0.529	96
8	Pivot, Long-lateral	0.781	86
9	Pivot, Travelling Gun (2)	0.554	>100
10	Travelling Gun (1)	0.651	>100
11	Travelling Gun	0.399	>100
12	Travelling Gun	0.422	>100

As indicated above, the application efficiencies of systems on the study farms is high, particularly when system capacity is closely matched to the water resource allocation. This result is possibly higher than expected but perhaps reflects several factors:

- The systems were professionally designed, so that equipment selection was based on design criteria to achieve relatively high CU values.
- Centre pivots generally have high CU values when correctly designed.
- CU values may be lower than indicated values due to higher than assumed impact of wind. As indicated in Section 3.2.1 wind speed values for Reporoa appear to be abnormally low and higher values are likely to reduce application uniformity.
- For some farms, particularly those currently using travelling gun irrigators and for several of the long-lateral and K-line systems, application uniformity may a constraint to the improvement of application efficiency and to overall productive response.

Section 3.5 presents a summary of sources of system non-uniformity and potential improvements in system application efficiency.

3.4 Seasonal Application Efficiency

As outlined in section 3.2.2 seasonal application efficiency was evaluated for the study farms based on estimates of water use from metering records and/or electricity consumption and calculated irrigation demand. The evaluation is based on water use and irrigation demand over the irrigation season (Nov-Apr). Seasonal application efficiency differs from farm application efficiency in that it takes into consideration the influence of rainfall. Irrigation during periods of rainfall reduces seasonal application efficiency, and therefore it is a general measure of efficiency of irrigation scheduling, particularly the initiation and completion of the irrigation cycle. Appendix K presents the details of the analysis of seasonal application efficiency.

Table 5 presents a summary of seasonal application efficiency based on metering records. Seasonal records were only available for four of the 12 farms (farms 3, 6, 7 and 11). All efficiency levels, apart from the 2000-01 season for farm 3, were greater than 100%, indicating that the irrigation demand exceeded water use. The results are higher than anticipated, but consistent with the relatively high farm application efficiencies in Section 3.3. However, they may also be due in part to incomplete water use records. The relatively few records and often incomplete state of records underlines a general constraint with the current water use recording conditions of resource consents.

Table 5: Seasonal Application Efficiency from Meter Readings

Farm No	Irrigation Method(s)	Water Use Efficiency (%)				
		1997-98	1998-99	1999-00	2000-01	2001-02
1	Long-lateral				na	na
2	Long-lateral				na	na
3	Long-lateral			na	84	123
4	Long-lateral	na	na	na	na	na
5	K-line				na	na
6	K-line				132	123
7	Pivot(2), K-line, Sprinkler				na	112
8	Pivot, Long-lateral				na	na
9	Pivot, Travelling Gun (2)			na	na	na
10	Travelling Gun (1)				na	na
11	Travelling Gun	130	124	172	116	na
12	Travelling Gun	na	na	na	na	na

Table 6 presents the seasonal application efficiency as calculated from electricity consumption records. Electricity records were readily available for eight of the 12 farms. Efficiency levels varied from less than 40% (farm 1, 2001-02 season) to more than 200% (farm 12, 2000-01) season. In general, efficiency levels are higher than expected, and apart from farm 1 for the 2001-02 season, tend to indicate that seasonal application depths are less than irrigation demand. This is possibly a function of irrigation management, such as the initiation of irrigation too late or stopping irrigation after insufficient rainfall.

The analysis of seasonal application efficiency indicates a general trend of under-irrigation, with irrigation depth (annual) less than irrigation demand. This is contrary to the common perception that pasture irrigation is generally inefficient. Under-irrigation may be occurring for a variety of reasons, such as labour constraints for system operation, high operating cost, limitations of current irrigation management practices. The impact of under-irrigation is a less than optimum pasture production, with implications for feed and farm management.

However, the analysis of seasonal application efficiency should be considered with some caution, due to the limitations of the data sets on which they are based. These limitations highlight the need for more reliable and accurate recording of water use to assess farm application efficiencies, along with local monitoring of rainfall and PET.

Table 6: Seasonal Application Efficiency from Electricity Consumption

Farm No	Irrigation Method(s)	Water Use Efficiency (%)				
		1997-98	1998-99	1999-00	2000-01	2001-02
1	Long-lateral				na	37
2	Long-lateral				74	107
3	Long-lateral			na	na	na
4	Long-lateral	na	na	119	106	177
5	K-line				na	na
6	K-line				125	127
7	Pivot(2), K-line, Sprinkler				na	na
8	Pivot, Long-lateral				na	104
9	Pivot, Travelling Gun (2)			87	106	114
10	Travelling Gun (1)				na	na
11	Travelling Gun	116	103	74	75	94
12	Travelling Gun	na	na	192	248	121

3.5 Improving Irrigation Performance

The primary irrigation management goal for dairy farms in the Waikato region should be to optimise pasture production within water allocations at minimum cost. Optimum pasture production from an irrigation perspective is achieved when applied water is matched to crop water demand as uniformly as feasible across the farm. Operating costs are minimised when the applied depth of water is sufficient to meet crop demand, with minimum losses to drainage. Application depths in excess of soil waterholding capacity and crop water demand (seasonal) increase losses to drainage and pumped volumes, hence operating costs i.e. energy, labour and maintenance. The two principal factors influencing system productive performance are application uniformity and irrigation management these factors can work independently or in combination.

For the study farms the key factors affecting application efficiency are:

- ***Long-lateral sprinkler location***; the application uniformity of long-lateral systems is dependent on the placement of sprinklers in subsequent irrigation events to achieve an adequate level of overlap. The design principle is to match the wetted area per irrigation cycle (sprinkler wetted area times number of irrigation events) to the irrigated area per sprinkler. It is up to the system operator to locate the sprinkler to achieve sufficient overlap between subsequent events. Typically for long-lateral system an overlap of at least 50% is required to achieve a CU of greater than 70%. While the systems are designed with a nominal return period, usually 6 days, with the required overlap to achieve acceptable uniformity, the actual return period is effectively longer (8-9 days). Likewise with the required overlap, the nominal application depth (36 mm) increases to 44-48 mm.

The application uniformity of long-lateral systems is dependent on operator skill in selection of sprinkler locations. Long-lateral operators commented on procedures for locating sprinklers, such as identifying the wetted area from the previous irrigation events in the early morning by the absence of dew on the grass, as the basis for selection of sprinkler placement. The uniformity of pasture growth is also an indicator of application uniformity, with areas of relatively low pasture height targeted for sprinkler placement.

- ***K-line performance (farm 5);*** the existing K-line system was extended to an adjacent leasehold property, increasing irrigated area from 82 to 100 hectares, without upgrading the system duty or resource consent. The expansion is adversely affecting system performance, most notably in terms of application uniformity. To improve system performance ad hoc changes were made to maintain operating pressures, with the installation of small sprinkler nozzles on some laterals and cycling of laterals. However in the longer term the system and consent should be updated to increase the specific capacity to meet demand.

- ***Centre pivot irrigator uniformity***; centre pivot irrigators are in principle capable of achieving CU values of greater than 90% under low wind conditions, as indicated by manufacturer distribution analysis. However, recent experience in the Hawkes Bay region, based on the distribution measurements using catch-cans, indicates the CU of some centre pivots was considerably lower than expected (less than 80%). The poor performance was attributed to poor sprinkler nozzle selection and low operating pressure, possibly indicating poor system design.

  While it was beyond the scope of this study to make direct measurement of distribution, the experience in Hawkes Bay suggests that the assessment of pivot performance may be worthy of further investigation.

- ***Wind affects;*** there is considerable uncertainty about the affects on system performance due to the possible inaccuracy of data for the local met site (as outlined in Section 3.2.2). However, it appears from local observations and data from Taupo that wind is likely to have a significant impact on irrigation system performance. The principal impact is a reduction in application uniformity and efficiency. More accurate information on local wind speed and frequency could provide the basis for selection of sprinkler type and spacing for system designers.

- ***Irrigation scheduling***; application efficiency is directly affected by irrigation scheduling, that is the application depth (mm) and return interval (days). Scheduling affected both farm and seasonal application efficiencies. High farm application efficiency was achieved when application depth and return interval was matched to crop water demand and soil water-holding capacity. Seasonal application efficiency is a function of both the system performance and the prediction of soil water conditions. The challenge in improving seasonal application efficiency is the determination of when to commence and stop irrigation. For systems with long return intervals, such as travelling gun irrigators (7-14 days) and long-lateral (8-9 days effective), it is necessary start the irrigation cycle at about 20-30% soil moisture deficit to avoid water stress towards to the end of the cycle. For the short rotation systems such centre pivots (1-2 day rotations) irrigation can commence at closer to the 50% deficit levels without incurring undue water stress.

Current irrigation management on all the study farms is based on personal experience and judgement of crop requirements. While the farmers undoubtedly have a good feel for the appearance of pasture growth, there is some uncertainty about soil moisture levels and the impact of rainfall. The soils in the area are of relatively low water-holding capacity and free draining, so there is a perception that it is better to start irrigating sooner rather than later to avoid running into stress, particularly during a prolonged dry period. This perception is especially true for the travelling gun irrigators and long-lateral systems, which have long return intervals. As discussed in the following Section 5, there is room for improvement with the development of on-farm monitoring of soil moisture and water use.

- ***Pressure variations due to elevation changes***; on five of the study farms (1, 7, 8, 9 and 12), there were significant elevation differences (15-30m) within the irrigated areas. Major elevation differences within the system will impact on sprinkler distribution uniformity unless they have been taken into consideration during the system design. A number of design and management strategies were adopted to overcome elevation difference, these were:
  - For long-lateral systems (farm 1), the design approach (reported by the supply company) is to design to the sprinkler with lowest operating pressure (furthest from pump or highest elevation), and to dissipate pressure to other sprinklers, through pipe selection, to maintain operation pressure and sprinkler uniformity.
  - On centre pivot irrigators (farms 7 and 8) pressure regulators are installed upstream of each sprinkler to maintain operating pressure.
  - On travelling irrigators a smaller gun nozzle diameter (farm 9 and 12) is selected for the higher runs to maintain wetted width.

One option, which was not included on any of the farms, was the use of variable speed control on the pump motor to maintain system duty. The variable speed control would be especially useful on farms with more than one irrigation method operating from the same pump (farms 7 and 9), as it would regulate system operating pressure, with change in flow conditions (number of irrigators operating simultaneously). The benefits of variable speed control would be a saving in energy and pump maintenance costs.

4 FINANCIAL COSTS AND BENEFITS OF IMPROVED IRRIGATION EFFICIENCY

The purpose of this section is to evaluate the response to irrigation and the potential costs and benefits of improvements in irrigation methods and management in the study area.

4.1 Irrigation Costs

The farm survey included collation of information on system capital and operating costs. While capital costs were relatively easy to recall for most farmers, it was more difficult to establish operating costs. This section presents a summary of capital costs and for some farms indication of operating costs (power and maintenance) and labour requirements.

Table 7 presents a summary of capital costs for the ten of twelve farms. Total capital costs varied between farms depending on irrigated area, irrigation methods and location of water source. Farms with remote water sources (farms 5 and 7) and/or long distance from electricity mainlines had higher capital costs. The cost for long-lateral and K-lines were within the range of $2000-3000/ha for systems with close proximity to water source. Farm 4 was an exception, as the only system that included on-farm storage, the cost of which is the equivalent of approximately $ 500/ha. The K-line system on farm 6, was upgraded from a previous travelling gun irrigator, therefore costs were lower than for an entirely new system. The cost of the centre pivot systems ranged from $4,400 to $5,300/ha. The higher cost for farm 7 is due, in part, to the distance (approximately one kilometre) of the water source from the farm. Capital costs for the travelling irrigators were approximately $2,000/ha for the two farms (11 and 12) with information on costs.

Table 7: Summary of irrigation system capital costs

Farm No	Irrigation method(s)	Total capital cost ($)	Irrigate area (ha)	Unit costs ($/ha)
1	Long-lateral	190,000	75	2,533
2	Long-lateral	202,000	82	2,463
3	Long-lateral	316,000	114	2,772
4	Long-lateral	445,000	125	3,560
5	K-line	345,000	100	3,450
6	K-line (1)	120,000	60	2,000
7	Pivots, K-line, Sprinkler	1,000,000	189	5,291
8	Pivot, Long-lateral	280,000	64	4,375
9	Pivot, Travelling Guns	na	140	-
10	Travelling Gun	na	24	-
11	Travelling Gun	82,300	40	2,058
12	Travelling Gun	150,000	74	2,027

Notes (1) Costs for upgrade of travelling gun irrigator to K-lines

Table 8 presents a summary of operating costs (power and maintenance) and daily labour requirements for system operation. Operating information is patchy, due in part to difficulties for farmers in separating specific irrigation system costs, and in part to the complexity of power pricing schemes. Labour requirements for the hand move methods, long-lateral and K-lines, were up to 4 hours per day, and were a high demand on farm management, which may be a factor in system application efficiency.

Table 8: Summary of operating costs and labour requirements

Farm No	Irrigation method(s)	Operating costs ($)	Maintenance costs ($)	Labour requirement (hr/d)
1	Long-lateral	na	na	1:30
2	Long-lateral	$100/day	na	na
3	Long-lateral	$12,000/yr	300/yr	2:30
4	Long-lateral	na	na	3:00 - 4:00
5	K-line	na	na	4:30
6	K-line	na	na	na
7	Pivots, K-line, Sprinkler	na	na	na
8	Pivot, Long-lateral	$90/day	na	na
9	Pivot, Travelling Guns	na	na	na
10	Travelling Gun	na	na	na
11	Travelling Gun	$3,700/yr	na	1:30
12	Travelling Gun	na	na	1:30 - 2:00

4.2 Productive and Financial Benefits

Pasture production response to irrigation

On one farm pasture production had been monitored during the 2001-02 season for irrigated and non-irrigated sections of the farm. This information provided monthly pasture production information for the calibration of a pasture production model based on soil water balance over the season, as outlined in Appendix O. The model was then used to general pasture production response to irrigation over the period 1998-2002 based on climate data for the Reporoa area. On the irrigated section of the farm total annual production of more than 18,000 kgDM/ha was recorded, while on the non-irrigated section production was less than 13,000 kgDM/ha.

Table 9 shows the annual pasture productive response to irrigation in the period 1998-2002 ranged from about 3,000 to 5,000 kgDM/ha. The water use efficiency is typically 12 kgDM per millimetre of irrigation, which is similar to previously reported values (Moir et al, 2000).

Table 9: Summary of pasture response to irrigation for 1998-2002

Year	Pasture production (kgDM/ha)	Irrigation demand (mm)	Pasture response (kgDM/mm)
1998-99	4,508	448	10
1999-00	5,179	392	13
2000-01	3,508	252	14
2001-02	3,048	252	12
Average	4,061	336	12

Financial costs and benefits of irrigation

Irrigation is one of a number of possible farm inputs to boost and maintain farm productivity and income (the other options include import of supplementary feeds such as silage, hay and concentrates, off-farm grazing and increased fertiliser applications). For the purposes of this study, a financial model was developed to evaluate the costs and benefits of irrigation in the Reporoa area. The model was used to determine the benefits of irrigation in terms of marginal returns ($/ha) and the returns to water ($/m^3). It is based on a typical farm model for the area and draws on information from the study farms, soil moisture modelling (Appendix B) and pasture production (Appendix O) as well as statistics for dairy farming in the south Waikato (LIC, 2003). Appendix N presents a description of the model, key inputs, parameters and assumptions, and output.

Table 10 presents a summary of the analysis of costs and benefits for the four principal irrigation methods. Note that this analysis is based on comparable pasture production for the methods, however in some circumstances there may differences between methods as discussed in the following section. The key points to note are:

- Stocking rate of 3.2 cows per ha
- Cow production of 362 kg MS/ha (both stocking rate and per cow production are a function of the increase in pasture production under irrigation as discussed in Appendix O).
- The analysis is based on a payout rate of $3.70 per kg MS.
- Irrigation expenses vary between irrigation methods (due to differences in capital, operating and labour costs) from $524 to $654 per hectare per annum. These are relatively high (compared to other locations) due in part to higher capital costs (for more remote water sources) and higher power costs (associated with fixed power charges)
- Marginal benefit of irrigation is the net returns per unit area ($/ha/yr) from $457 for centre pivots to $327 for K-lines. However, the returns are high reflecting the importance of irrigation in the area, and strong contribution of farm incomes and profits.
- The unit cost of water range between 15 to 18c per cubic metre, which is relatively high for surface water supplies, but are largely due to higher capital and operating costs.
- Net returns to water range between 9 to 13 cents per cubic metre.
- The cost per kgDM production at 12 to 16c per kg are considerable higher than reported values for other locations (typically less than 10c/kgDM), however this is largely due to higher operating costs. In comparison off-farm supplementary feeds such as silage and concentrates are typically in the order of 20-30c/kgDM.

Table 10: Summary of irrigation financial costs and benefits

Financial Analysis [1]	K-lines	Long-lateral	Centre pivot	Travelling gun
Stocking Rate (cows/ha)	3.2	3.2	3.2	3.2
MS Production (kg MS/cow)	362	362	362	362
MS Production (kg MS/ha)	1,141	1,141	1,141	1,141
Total Income	4,553	4,553	4,553	4,553
Farm Expenses:				
Working Expenses:	2,338	2,338	2,338	2,338
Irrigation Expenses:				
Fixed costs	263	255	293	219
Operating costs	391	342	231	361
Total Irrigation Expenses	654	597	524	579
Total Expenses	2992	2935	2862	2918
Cash Surplus	1561	1618	1691	1635
Non cash Adjustments:	-663	-663	-663	-663
Economic Farm Surplus:	898	955	1028	973
Marginal Benefits	**327**	**384**	**457**	**401**
Water cost ($/m^3)[2]	0.18	0.17	0.15	0.16
Net returns ($/m^3)	0.09	0.11	0.13	0.11
Cost/kgDM	0.16	0.14	0.12	0.14

Note (1) all figures are $/ha unless otherwise stated

4.3 Financial Benefits of Improved Irrigation Efficiency

As indicated above there are a number of potential improvements in system performance. The purpose of this section is to evaluate the financial costs and benefits of these improvements. Potential improvements in irrigation efficiency are listed below:

i) Improved application uniformity

Pasture production is a function of application uniformity, as uniformity decreases a higher proportion of irrigated area suffers from moisture stress (assuming that the irrigation schedule is matched to irrigation demand). Analysis of the relationship of soil water balance, pasture production and application uniformity indicates that there is an approximately 25 kgDM/ha change in pasture production per unit change (%) in application uniformity (Appendix P).

Based on the financial analysis in Section 4.2, the impact of changes in application were evaluated on marginal benefits for the four irrigation methods. As indicated in Figure 3 the response is similar for all four methods, with an increase in marginal benefits of approximately $100/ha with an increase in application uniformity from 60 to 80%.

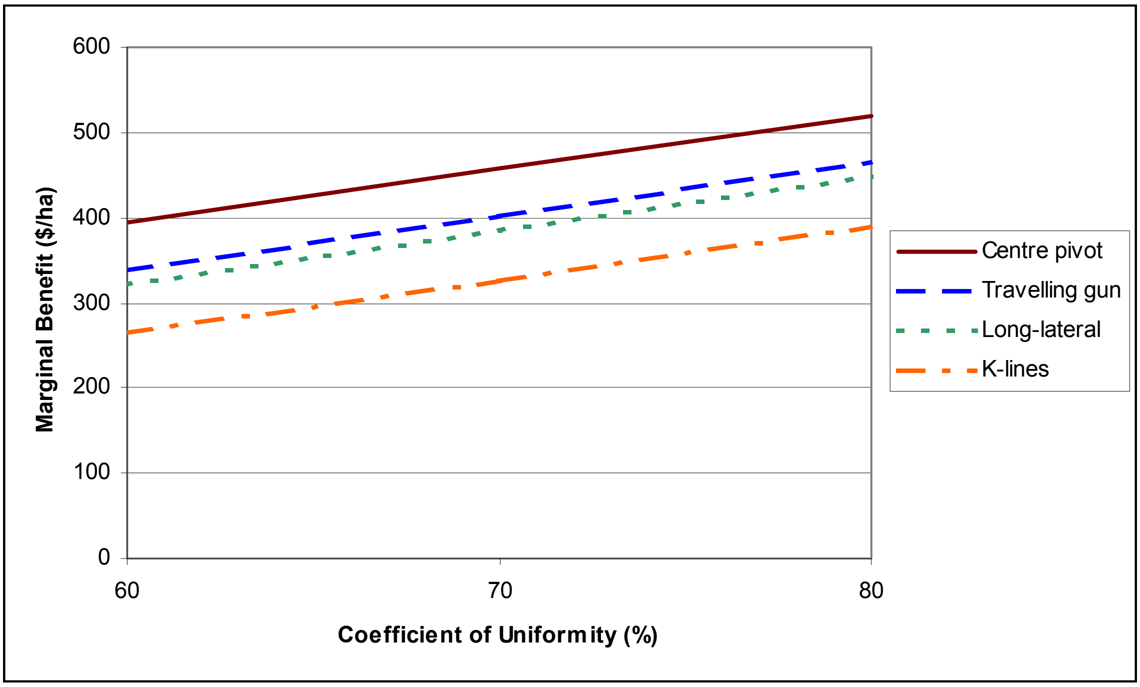

Figure 3: Relationship between application uniformity and marginal benefits

As discussed in Section 3.1.1 the factors that influence application uniformity are system characteristics, such as sprinkler type and spacing, and operating conditions i.e. operating pressure and pressure variation between discharge points. The system characteristics are largely predetermined during the system design with selection of system type and components. There is little that can be done retrospectively to improve basic system performance short of upgrading system type. The hand move systems, i.e. K-lines, long-lateral and travelling gun irrigators are typically capable of achieving CU values within the range of 65-75% under ideal field conditions. Centre pivot systems are capable of achieving CU values of greater than 80% under similar conditions.

The operational factors that directly impact on application uniformity are:

- Sprinkler location for K-line and long-laterals; this is largely a system management issue related to the placement of sprinklers and laterals to achieve sufficient overlap to maintain uniformity.
- Operation during periods of high wind, at wind speed greater than 12 km/hr (6 m/s)
- Excess pressure variations between sprinklers; while in part a system design issue, it may also be affected by system operation, with the selection of a number of sprinklers operated simultaneously or selection of irrigator runs.

The cost of improving application uniformity will vary between systems, in some cases such as sprinkler placement for long-lateral systems, it requires more diligent operation with little additional cost, while in others it may require equipment upgrades, for example, system pressure regulation.

The above benefits indicate that there is a strong financial benefit in improving application uniformity. For example a 10% improvement in CU with the installation of variable speed pump control (typically costing less than $10,000), on a 70 ha farm could increase returns by about $ 3,500 per year, with a payback within 4-5 years.

ii) Improved irrigation scheduling

Application depths in excess of irrigation demand leads to water losses to drainage. For the farms within the Reporoa area, excess irrigation appears to be largely a result of irrigation scheduling, that is, starting irrigation before a threshold level of soil moisture depletion is reached or continuing to irrigate once this level is reached following rainfall. The financial impact of over irrigation is to increase irrigation operating costs, with additional costs due to pumping, labour and system maintenance.

Figure 4 shows the relationship between application efficiency and marginal returns. As application efficiency declines marginal benefits decline due to increased costs. Marginal benefits decreased by about $40/ha per ten percent decrease in application efficiency. However it should be noted that benefits are still positive even at application efficiencies of 55%, which reflects the relatively low operating costs compared to the potential benefits. This indicates that the cost of system operation is not a strong incentive to improving application efficiency, and in some cases poor application uniformity may be compensated by higher total application (hence lower efficiency) particularly during periods of low water demand or intermittent rainfall.

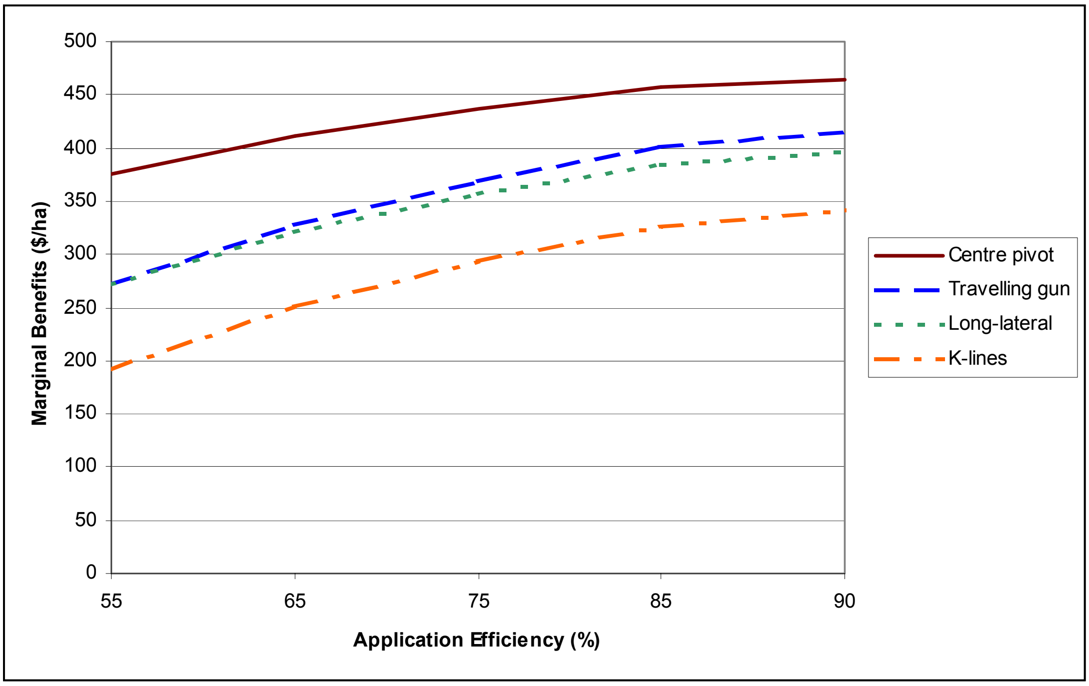

Figure 4: Relationship between application efficiency and marginal benefits

The analysis of seasonal application efficiency (Section 3.2.2) showed that apart from one farm (1), high efficiency levels were achieved. Possible explanations for the high efficiency levels are that for most farms, particularly those with hand-move irrigation systems (long-lateral, K-lines and travelling gun irrigators), labour savings is an incentive to improving application efficiency and secondly for some farms, other supplementary feed options are utilised to complement irrigation benefits.

The high application efficiency levels reported in Section 3.2.2 indicates that on some farms under-irrigation is occurring, which is reducing potential pasture yields. The cost of under irrigation will be both in terms of reduced milk solids production and/or the need to utilise higher levels (and therefore cost) of supplementary feeds. Under irrigation may be a result of limitation of the irrigation system, particularly travelling gun irrigators with long return intervals and limitations of current irrigation scheduling. Improvements in irrigation methods and scheduling on these farms will produce an increase in productivity and returns.

There is potential for improvement in irrigation scheduling in the Reporoa area. Current on-farm experience needs to be complemented with quantitative measurement of soil moisture and climate data. However, experience elsewhere indicates that for scheduling programmes to be successful they need to be practical and easily interpreted, so that farmers can readily make decisions on when to start and stop an irrigation cycle. A couple of options that have been relatively successful in other parts of the country are:

- Soil moisture monitoring service - installation of neutron probes at strategic locations (based on soil types) around the farm, which are routinely monitored (weekly) (by a service provider) during the irrigation season. The results of the monitoring are provided in summary form to the farmer along with a recommendation on irrigation schedule. Such a service is provided by Hydroservices working out of Hastings. The cost for a typical dairy farm (with 3 neutron probes) would be in the order of $ 1,200 per year. The advantages of this approach are that it provides direct on-farm measures and a personalised farm report.

- Community based monitoring service - monitoring of soil moisture on representative farms within the area, along with climate parameters (for calculation of PET). This information is used as a reference base, along with irrigation schedule and rainfall, to determine the irrigation of other farms in the district. One such system is Irrilinc, which is currently being used in Otago and Canterbury. The system is based on network approach, with telemetry of soil and climate data to a central location for processing and storage; this data is then accessible to individual farmers. Provisional estimates indicate that the establishment of a community monitoring service in Reporoa (based on 3 representative sites) would have a capital cost in the order of $15,000 and initial training costs in the order of $5,000. In addition to equipment costs there are on-going operating costs for data acquisition and network costs estimated to be less than $200 per farm per year.

- Soil moisture monitoring; direct on-farm soil moisture monitoring, by use of in situ equipment such as Aquaflex, TDR and tensiometers or use of portable soil moisture monitoring equipment. But for most farmers this is not a practical option as they are committed to other farm activities.

5 CONCLUSIONS AND RECOMMENDATIONS

This study is a contribution to the progressive development of water resource management in the Waikato region. It follows on from previous studies that established crop water requirements and evaluated the allocation processes. It provides a higher level of resolution in assessing current levels of efficiency and understanding the links between irrigation systems and management, and the productive and financial response to irrigation on dairy farms in the south Waikato. The following subsections present a summary of the study conclusions and recommendations.

5.1 Conclusions

- Constraints; the analysis presented in this report has been completed within data and information constraints, this includes current estimates of PET within the study area and farm water use records. Where necessary it adopted reasonable assumptions and parameters in the development of models for assessment of efficiency, productivity and financial costs and benefits.
- Crop water requirements; the analysis of crop water requirements based on local soil and climate data is consistent with the earlier Landcare (1997) study, and with local irrigation management practices.
- Water allocations; the current daily allocation rate (l/s/ha) is consistent with crop water requirements and should be considered a 'reasonable' basis for efficient resource allocation and use.
- Irrigation systems; the main irrigation methods used on dairy farms in the south Waikato are; long-lateral, K-lines, centre pivot and travelling gun irrigators.
- Application uniformity; estimates of CU ranged from less than 60% for travelling gun irrigators, long-lateral and K-lines to more than 80% for centre pivots. The key factors affecting uniformity were system type, wind and variability of operating pressure.
- Farm application efficiency; assessment of application efficiency, based on water allocation, system design and irrigation management, indicates that during periods of peak water demand it is greater than 80% for most farms. On some farms, under irrigation may be occurring due to system and management limitations, particularly for the travelling gun irrigators. On these farms, improvements in system application efficiency are likely to improve pasture production and returns.
- Seasonal application efficiency; while the assessment of seasonal application efficiency was constrained by data limitations it indicated relatively high efficiency levels (apart from one farm). For some farms, high efficiency levels are a function of irrigation system or schedule limitations (for example long return intervals). On others it may be a function of the high labour requirements, for system operation such as for long-laterals and K-lines.
- Key factors for improving application efficiency are; application uniformity (including sprinkler location (long-laterals), system duty (K-line) and wind affects) and irrigation scheduling.
- Irrigation costs; unit area capital costs of systems were; travelling gun irrigator $2,000/ha, long-lateral and K-lines $2,500-3,000/ha and centre pivot $4,500-5,500/ha. Costs varied between systems dependent on type and infrastructure costs, particularly for pipelines and power supply.
- Irrigation productivity; the average productive response to irrigation is in the order of 4,000 kgDM/ha, or the equivalent of 12 kgDM per millimetre of irrigation.

- Irrigation benefits; the marginal benefits of irrigation ranged from $330 to $450/ ha for K-lines and centre pivot irrigation respectively. The net returns to water are in the order of 10 cents per cubic metres.
- Improving application uniformity; there is an increase of approximately 25kgDM/ha per unit (%) in system coefficient of uniformity, or the equivalent of $4/ha/%CU. Management or material measures to increase system such as sprinkler locations on long-laterals, use of variable motor speed control (regulation of system duty) and pressure regulation, produce a positive financial benefit.
- Improving irrigation scheduling; marginal returns decline with a reduction in application efficiency for all four irrigation methods, however they still remain positive ($200/ha) at efficiencies as low as 50%. This indicates that operating costs are not likely to be a major incentive to water conservation, and the high efficiency indicated above is more likely to be a function of constraints on labour.

5.2 Recommendations

Based on the report findings the following are recommended:

vi) Water use records; the procedures and perhaps methods for recording water use should be reviewed and updated. The water use records should form the basis of assessment of seasonal application efficiency, however they are currently incomplete or inaccurate for many consent holders. The current requirement for submission of daily records appears to be a difficult condition for many consent holders to consistently fulfil. Options for improvements include weekly records, use of dataloggers on larger consents, and in some cases remote access to records.

vii) Seasonal water use; the current consent process is primarily focused on preservation of surface water flows. Consideration should be given to the development of seasonal allocations based on irrigation demand that incorporates rainfall and PET elements. This may ultimately include allocations incorporating annual volume components.

viii) Application efficiencies; the results for farm and seasonal application efficiency are both surprising and encouraging. But these results are based on an empirical approach, and on a number of assumptions on system design and management. These findings could be further refined, with an evaluation of application under field operation conditions. An on-farm irrigation audit methodology is currently being developed (a Sustainable Farming Fund project based in Hawkes Bay), which incorporates use of catch-cans for measurement precipitation rates. The next stage in the assessment of on-farm efficiency factors should consider the application of the audit methodology.

ix) Irrigation management; on-farm irrigation scheduling practices should be promoted to encourage water use productivity and efficiency. Current on-farm practices could be improved with the establishment of a local network, incorporating representative monitored sites (climate and soil moisture) to provide irrigators with a quantitative assessment of irrigation demand. There is an existing 'informal' irrigation group in the district, which meets regularly through the irrigation season. This group may be interested in formulating a project to establishing a local irrigation network. There are potential funding sources for such a project, such as the Sustainable Farming Fund, with contributions from EW, district councils and producer organisations.

x) Performance standards; current water resource consent allocations are based upon an assumed application uniformity (CU of 70%) and application efficiency (AE of 85%). However, there are no explicit performance standards specified for system design or management. The specification of irrigation performance standards as a resource condition, for example CU and DU for system type, would ensure systems are designed to meet minimum uniformity and efficiency levels. It would also establish a measurable benchmark for system assessment.

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Appendix A: Summary of Farm Survey Results

Table A-1 presents a summary of the water resource consent details for the study farms as supplied by Environment Waikato. Note that in the case of farm 3, the irrigation duty is a combination of three takes, due to the farm comprising of three adjacent titles (two freehold and one leasehold).

Table A-1 Summary of Water Resource Consents

Farm No.	Water source river/stream	Allocation (m^3/d)	Allocation (l/s)	Daily (hr)
1	Waikato	4,560	87	24
2	Ruatawiri	3,750	87	7pm-7am
3	Torepatutahi	2,600	60	24
"	Torepatutahi	4,700	77	24
"	Torepatutahi	1,200	33	24
4	Torepatutahi	6,250	78	24
5	Waikato	4,030	93	24
6	Waikato	3,000	14	24
7	Waikato	8,640[3]	100	24
8	Waikato	4,320	72	24
9	Kaiwhitiwhiti	6,700	83[1]	24
10	Kaiwhitiwhiti	1,350	17[2]	24
11	Ruatawiri	1,380	22	24
12	Waikato	2,700	38	24
	Total	**55,180**	**861**	

Notes (1) Take rate is 83 l/s but restricted to 66 l/s when consent 950656 is exercised,
(2) Take rate ceases when stream flow is less than 700 l/s,
(3) Consent includes annual allocation of 1,130,000 m^3/yr

Table A-2 presents a summary of farm areas total, effective and irrigated, as described during the farm surveys. In some cases farmers supplied farm maps showing irrigated areas and system layout.

Table A-2 Summary of Farm and Irrigated Areas

Farm No.	Areas (ha) Total	Areas (ha) Effective	Areas (ha) Irrigated
1	78	75	75
2	141	132	82
3	173	169	114
4	133	125	125
5	104	100	100
6	62	60	60
7	400	375	189
8	87	78	64
9	470	370	140
10	126	125	24
11	82	74	40[(1)]
12	94	92	74
	1,950	**1,775**	**1,087**

Note (1) Irrigated area reported to vary from 30 to 40 ha

Appendix A: Summary of Farm Survey Results

Table A-3 presents a summary of specific capacity (l/s/ha) and mean daily application depth (mm/d). Specific capacity is calculated on daily water allocation (m^3/d) and irrigated area (ha), it varied from less than 0.4 to more than 0.8 l/s/ha. Based on current EW allocation criteria (Landcare, 1997), specific capacity should be about 0.6 l/s/ha.

Table A-3 Summary of Specific Capacity and Application Depth

Farm No.	Irrigated Area (ha)	Allocation (m^3/d)	Specific Capacity (l/s/ha)	Application Depth (mm/d)
1	75	4,560	0.704	6.1
2	82	3,750	0.529	4.6
3	114	8,500	0.863	7.5
4	125	6,250	0.579	5.0
5	100	4,030	0.466	4.0
6	60	950	0.579	5.0
7	189	8,640	0.529	4.6
8	64	4,320	0.781	6.8
9	140	6,700	0.554	4.8
10	24	1,350	0.651	5.6
11	40	1,380	0.399	3.5
12	74	2,700	0.422	3.6
	1,087	**Average**	**0.588**	**5.1**

Table A-4 Irrigation Methods and Areas

Farm No.	System(s)	Area (ha)	Installed (yr)	Company
1	Long-lateral	47	2001	Bosch
"	Long-lateral	28	2002	"
2	Long-lateral	82	2001	"
3	Long-lateral	57	2000	"
"	Long-lateral	47	2001	"
"	Long-lateral	10	2002	"
4	Long-lateral	125	1996	"
5	K-lines	72	1999	?
"	K-lines	28	2002	?
6	K-lines	60	2000[2]	?
7	Centre-pivots (2)	151	2001	Bosch
"	Easi-rain	30	2001	WCS[3]
"	Fixed Sprinkler	8	2001	WCS
8	Centre-pivots	42	2001	Bosch
"	Long-lateral	22	2001	Bosch
9	Centre-pivot	88	2001[4]	Bay Irrigation
"	Travelling gun	52	1996	Bay Irrigation
10	Travelling gun	24	NA	Bay Irrigation
11	Travelling gun	40	1982[1]	?
12	Travelling gun	74	1983	?

Notes: (1) original system installed in 1982, upgraded to travelling gun irrigator in 1999, (2) system upgraded from travelling gun system in 2000, (3) Water Control Solutions, (4) system upgraded from travelling gun irrigator installed in 1996

Appendix A: Summary of Farm Survey Results

Table A-4 presents a summary of irrigation methods used on the study farms. There were four main systems; centre pivots, long-lateral, K-line (or Easi-rain) and travelling gun irrigators. On one farm (7) there was a small area (8 ha) of fixed sprinklers for the irrigation of a corner around a pivot. The earliest systems installed were travelling gun irrigators installed in the early 1980's. However the majority of systems were installed in the past five years, probably reflecting the relatively recent interest in irrigation for the dairy industry. This interest is possibly a function of relatively high payout rate and a general drive within the industry towards increased productivity.

Appendix B: Soil Water Balance Model

The Conceptual Soil Moisture Model is based on the following equations, for conservation of mass and daily time periods:

Inflow = Outflow + Change in Storage

$$I_t + P_t = DR_t + AET_t + (PAW_t - PAW_{t-1}) + (PAWmax_{t-1} - PAWmax_t)$$

Rearranging:

$$PAW_t = PAW_{t-1} + P_t + I_t - AET_t - DR_t + PAWmax_t - PAWmax_t \quad (1)$$

Where:

PAW_t	is the level of available soil moisture (mm) for day t
PAW_{t-1}	is the level of available soil moisture (mm) for day t-1
P_t	is the rainfall rate (mm/day) for day t
I_t	is the irrigation rate (mm/day) for day t
AET_t	is the actual evapotranspiration rate (mm/day) for day t
DR_t	is the rate of movement of water away from the root zone to deep drainage (mm/day) caused by PAW levels exceeding PAWmax for day t
PAW_{max}	is the maximum available soil moisture (mm) for day t or t-1 in the root zone

Equation A-1 is used to calculate the daily soil moisture levels through the simulation period.

Available Soil Moisture

For this study the following assumptions and values were adopted:

- Profile readily available water (Praw) as the available soil moisture level. Praw is estimated from the volumetric water content difference between –10 kPa and –1500 kPa in the 0-0.4 m layer, and between –10 kPa and –100 kPa in lower layers (Webb et al, 1995).
- Crop rooting depth was fixed at 0.5 metres
- The maximum available soil moisture is the drained upper limit, in this case assumed to be the water content at –10kPa.
- The rootzone depth was assumed to be constant at 0.5m, therefore PAWmax remained constant.

Evapotranspiration

Actual evapotranspiration (AET) is the effects of evaporation from the soil and transpiration from the crop. The model considers AET to be a function of the atmospheric demand for water (ET_{ref}), crop characteristics (Kc) and the soil moisture content in the crop root zone (PAW_{fac}).

$$AET = \int (ET_{ref}, PAW_{fac}, Kc) \quad (2)$$

Atmospheric demand is characterised by the evapotranspiration rate (ET_{ref}) which occurs when evapotranspiration for a reference crop (usually pasture) is limited only by the meteorological conditions. For this study ET_{ref} was estimated from daily climate data using the Penman/Monteith method.

Appendix B: Soil Water Balance Model

Crop coefficients are used in the model to calculate the potential evapotranspiration (PET) for a specific crop with the following equation.

$$PET = ET_{ref} * Kc \quad (3)$$

The Kc is a crop specific coefficient incorporating the joint effects of the stage of development of the crop and the degree of crop cover. For this study it was assumed that there was full ground cover. The Kc value adopted was 1.0, which is an average value for rotationally grazed pasture with height range of 0.15 to 0.30 m (FAO, 2000).

The rate at which a plant transpires is restricted at low soil moisture levels. There are various empirical approaches to defining the relationship between AET and soil moisture levels. The approach adopted in the model is to use a reduction factor (ET reduction factor) to define the threshold soil moisture level below which AET decreases. The ET reduction factor is the ratio of PAW to PAW_{max} (as percentage), for which a value is selected below which AET reduces linearly to zero. For this study an ET reduction factor of 15 was adopted.

Drainage

If the volume of water infiltrated exceeds the volume required to restore PAW to the drained upper limit, the excess is assumed to drain beyond the root zone one time step (day). The drainage volume is given by:

$$DR = PAW + I + P - PAW_{max} \quad (4)$$

Rainfall

For this study all precipitation was assumed to be effective, that is infiltrated the soil.

Irrigation

The depth of water applied and timing of irrigation is determined by the irrigation rules. The rule options include:

- No irrigation
- Irrigation at a specified level of soil moisture depletion to a specified depth or soil moisture level
- Irrigation at a specified depth and return interval

For this study the rule option adopted was irrigation at a specified depth (approximately 50% of Praw) and specified return period. The return period was established by trial and error, until a solution was acceptable to the probabilistic frequency of soil moisture levels. These were a soil moisture level greater than 25% of Praw for 100% of the time and soil moisture level greater than 90% of Praw for 50% of the time.

The model takes account of the non-uniformity of irrigation applications. It uses the Christiansen's Uniformity Coefficient as the measure of application uniformity. The CU along with the application depth, determines how much of the applied water is actually retained in the crop root zone, and losses to drainage. For this study a CU of 70% was adopted, this is a typical value for well managed sprinkler systems. However, it should be recognised that some systems, particularly well designed and managed centre pivots are comparable for achieving CU values higher than 70%.

Appendix B: Soil Water Balance Model

Model Outputs

The model outputs are:

- Daily AET
- Daily irrigation application depth (IRR)
- Daily drainage
- Daily soil moisture level

For this study water allocations, daily and peak were calculated from the model results as the mean monthly and maximum annual (calendar year) values respectively.

The following appendices (C to I) present a summary of key input and outputs for the model, including:

- Soil characteristics for the case farms (Appendix C).
- Comparison of PET at Reporoa, Rotorua and Taupo (Appendix D).
- Comparison of mean monthly wind speed for Rotorua, Taupo and Reporoa (Appendix E).
- Comparison of measured and monitored soil moisture levels at Reporoa over the period 1999-02 (Appendix F).
- Soil water balance results for Taupo Pumice (Praw = 75mm) and irrigation schedules for 1999-02 (Appendix G).
- Summary of climate data (PET and rainfall) (Appendix H).
- Summary of irrigation demand (Appendix I).

Appendix C: Summary of Soil Types

The table below lists a summary of the soil types and waterholding characteristics for the study case farms. The soils were very similar for all farms, for the evaluation of soil water balances (Appendix B) the Praw-mid value, 87 mm was adopted.

Table C-1: Soil type and waterholding characteristics for the study farms

Farm No.	Series	Type	Praw_mid	Praw_min	Praw_max	Paw_mid	Paw_min	Paw_max
1	Taupo	Silty sand	87	75	99	200	150	249
2	Taupo	Silty sand	87	75	99	200	150	249
3								
4	Taupo	Silty sand	87	75	99	200	150	249
5	Taupo	Silty sand	87	75	99	200	150	249
6	Whenuaroa	Gravelly sand	87	75	99	120	90	149
7	Taupo	Silty sand	87	75	99	200	150	249
8	Taupo	Silty sand	87	75	99	200	150	249
9	Taupo	Silty sand	87	75	99	200	150	249
10	Taupo	Silty sand	87	75	99	200	150	249
11	Taupo	Silty sand	87	75	99	200	150	249
12	Whenuaroa	Sand	87	75	99	120	90	149

Appendix D: Comparison of Potential Evapotranspiration (mm/d/mth) for Reporoa and Rotoura for the period 1999-02

The figure below plots the mean monthly PET (mm/d)values for sites are Reporoa and Rotorua. Note the consistently lower values at the Reporoa site, as discussed elsewhere in this report.

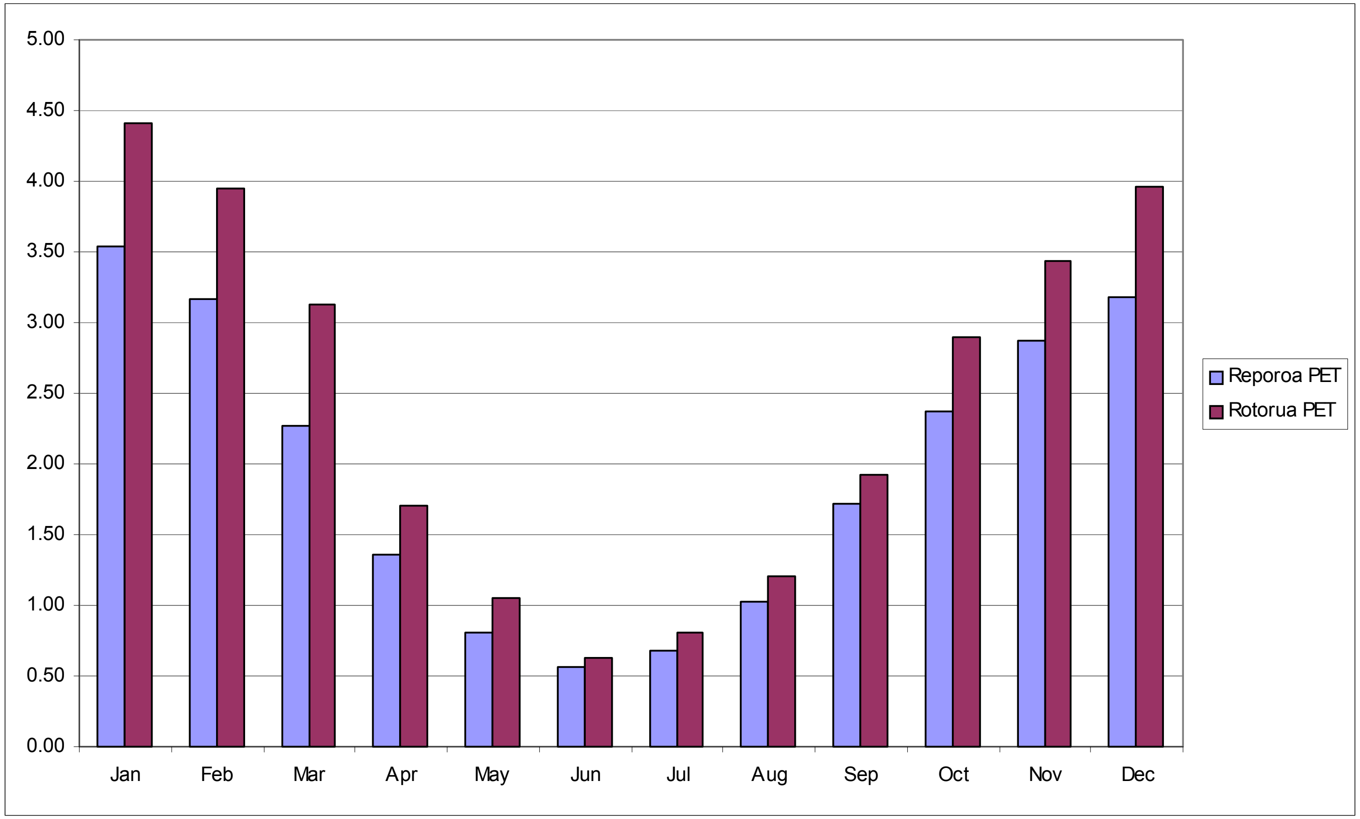


Figure D-1 Comparison of PET (mean monthly (mm/d)) for Reporoa and Rotorua

Appendix E: Comparison of Mean Monthly Wind Speed for Rotorua, Taupo and Reporoa

Figure E-1 shows the comparison for mean monthly wind speed (m/s) for sites at Reporoa, Rotorua and Taupo. Given the relatively close proximity of the three sites, Reporoa data appears to be abnormally low.

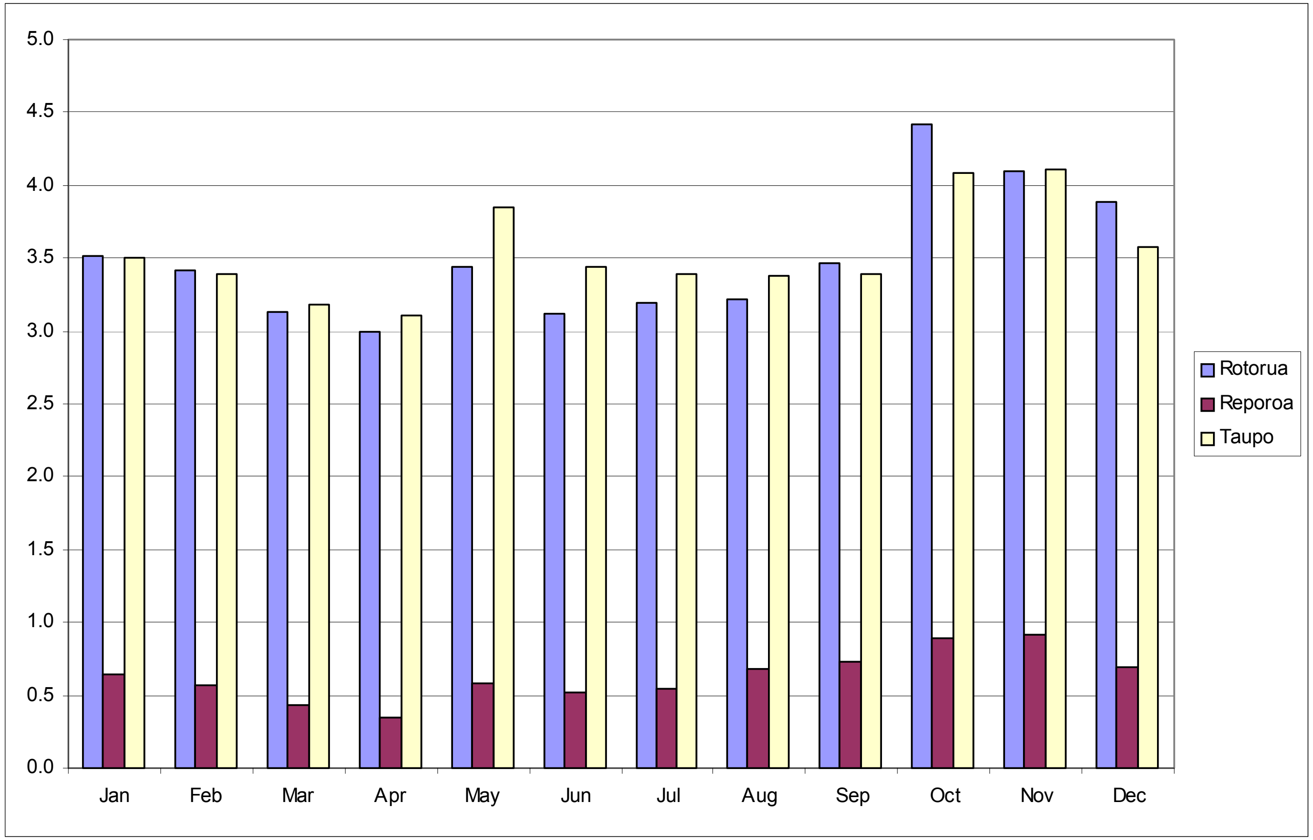


Figure D-1 Comparison of mean monthly wind speed (m/s) for Reporoa, Rotorua and Taupo

Appendix F: Comparison of Measured and Monitored Soil Moisture Levels at Reporoa over the period 1999-02

Figure F-1 shows the relationship between measured and modelled soil moisture levels at the EW climate station at Reporoa, over the 1999-02 period, along with rainfall. It indicates a reasonably closed relationship between the measured and modelled values, and similar responses to rainfall.

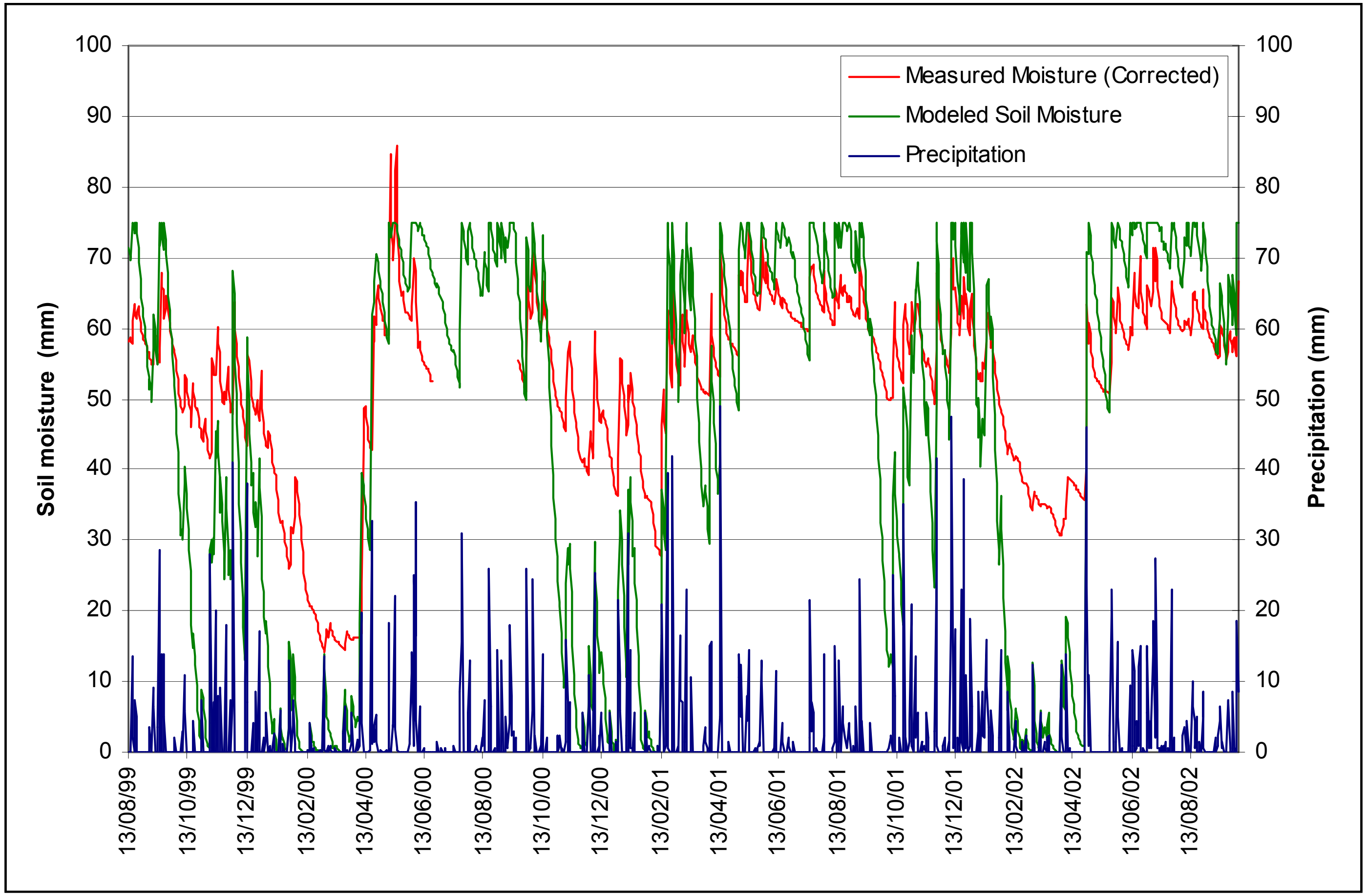


Figure F-1 Comparison of measured and modelled soil moisture levels at Reporoa

Appendix G: Soil Water Balance Results for Taupo Pumice (Praw = 75mm) and Irrigation Schedules for 1999-02

Figure G-1 shows the plot of soil moisture frequencies for non-irrigation and four irrigation regimes; 15mm/5days, 20mm/5days, 28mm/5days and 36mm/6days. EW water allocations are based on the equivalent of 28mm/5days (5.7 mm/d). The long-lateral and K-line system are typically designed for application depths of 30-36 mm per nominal 6 day return interval. The figure shows that these regimes meet the likely water demand.

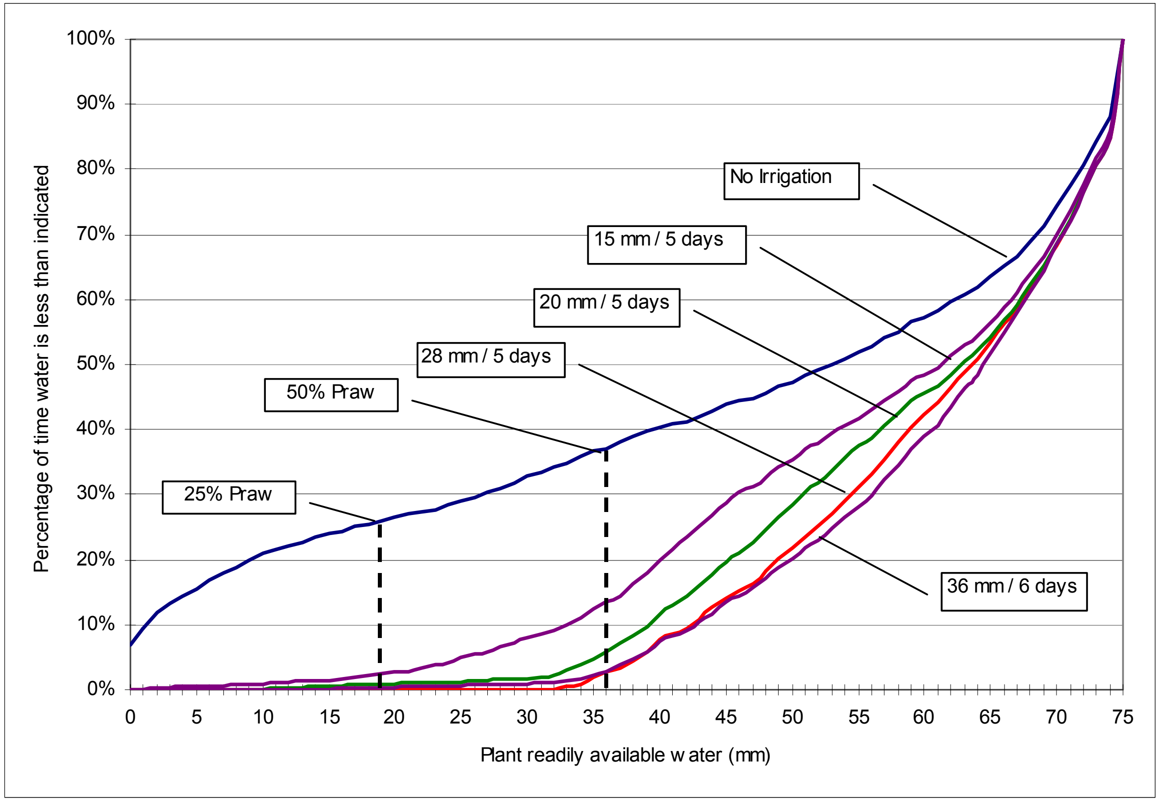


Figure G-1 Plot of soil moisture model levels for non irrigation and irrigation regimes for Reporoa

Appendix H: Summary of ReporoaClimate Data

Table H-1 and Figure H-1 lists the monthly rainfall at Reporoa site for irrigation seasons (Jul-Jun) in the period 1998-02, based on a composite of data from the EW and Sylvan Lodge sites.

Table H-1: Rainfall Monthly Summary (mm)

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
1998-99	102	62	38	106	50	103	159	10	50	69	101	103	951
1999-00	102	62	86	32	150	87	49	5	33	95	81	92	872
2000-01	75	61	84	64	56	81	68	135	74	86	96	25	903
2001-02	56	56	40	109	106	219	85	20	38	101	67	92	986

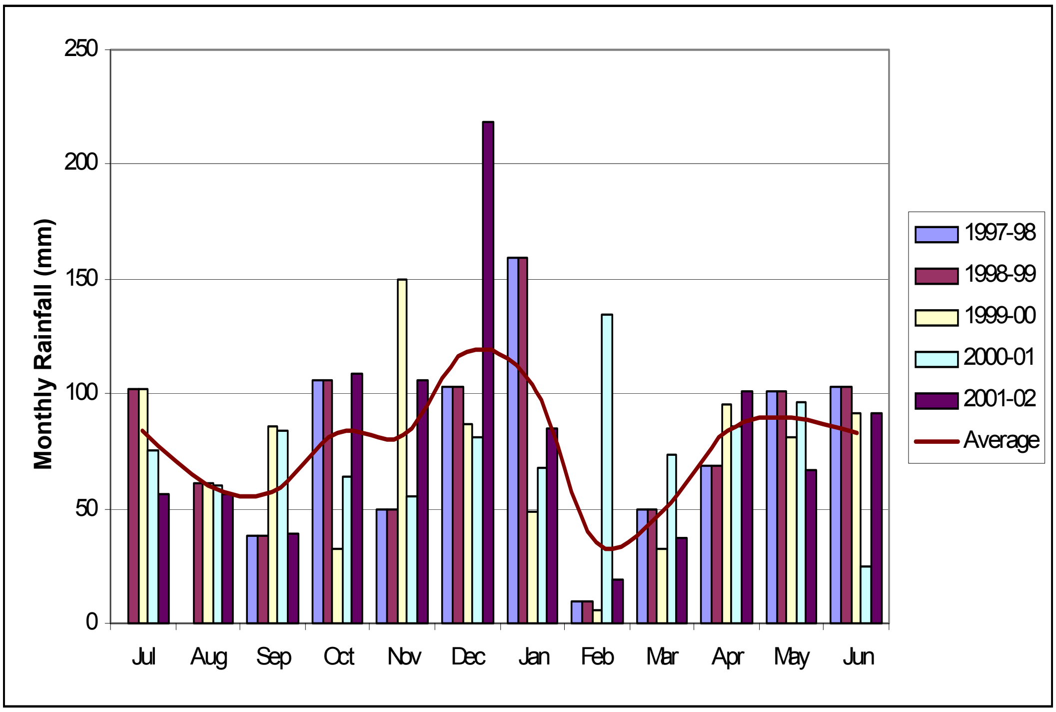


Figure H-1: Plot of monthly rainfall (mm) at Reporoa 1997-98

Table H-2 and Figure H-2 show the monthly PET values for Reporoa for irrigation seasons (Jul-Jun) in the 1997-02 period, based on corrected values for wind speed.

Table H-2: PET Monthly Summary (mm)

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
1997-98	24	38	68	89	119	134	141	117	65	39	26	17	876
1998-99	22	37	68	89	119	134	141	117	65	39	26	17	872
1999-00	22	37	64	93	105	128	129	123	89	44	28	19	881
2000-01	25	38	59	91	102	113	129	93	90	57	33	23	854
2001-02	29	39	65	80	89	97	128	97	94	56	33	21	828

Appendix H: Summary of ReporoaClimate Data

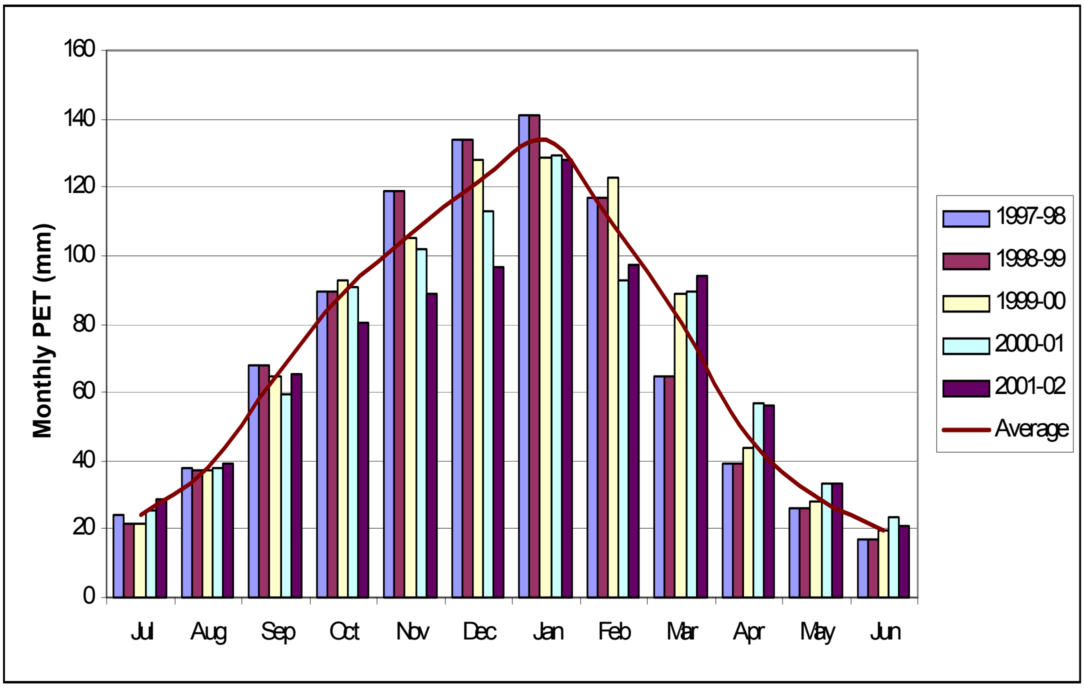


Figure H-2: Monthly PET (mm) at Reporoa

Appendix I: Summary of Irrigation Demand at Reporoa

Table I-1 and Figure I-1 show irrigation demand, based on soil moisture model results for the period 1998-02. Based on the limited records, annual demand is approximately 330, with peak irrigation demand generally in the late summer-autumn period.

Table I-1: Irrigation Monthly Demand (mm)

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
1998-99	0	0	28	28	84	84	84	84	56	0	0	0	448
1999-00	0	0	0	56	28	28	112	112	56	0	0	0	392
2000-01	0	0	0	28	56	56	28	56	28	0	0	0	252
2001-02	0	0	28	0	28	0	28	84	56	28	0	0	252
											Average		336

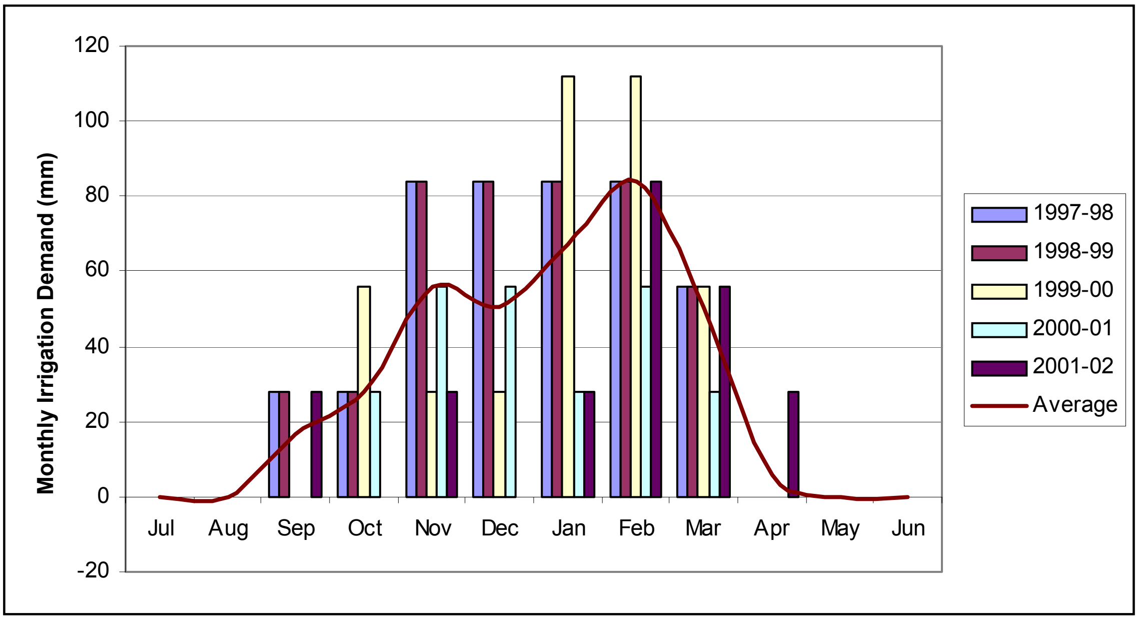


Figure I-1: Irrigation demand at Reporoa (mm/mth) 1998-02

Table I-2 and Figure I-2 illustrate the frequency and occurrence of drought days, that the number of days soil moisture levels are less than 25% of Praw, in the period 1998-02. On average there are nearly 100 drought days per year, with highest frequency in the Feb-Mar period.

Table I-2: Summary of Drought Days

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
1998-99	5	17	14	13	23	21	6	99
1999-00	15	4	2	31	29	31	8	120
2000-01		24	26	17	12			79
2001-02	8				28	31	24	91
Average	8	16	14	19	23	26	11	98

Appendix I: Summary of Irrigation Demand

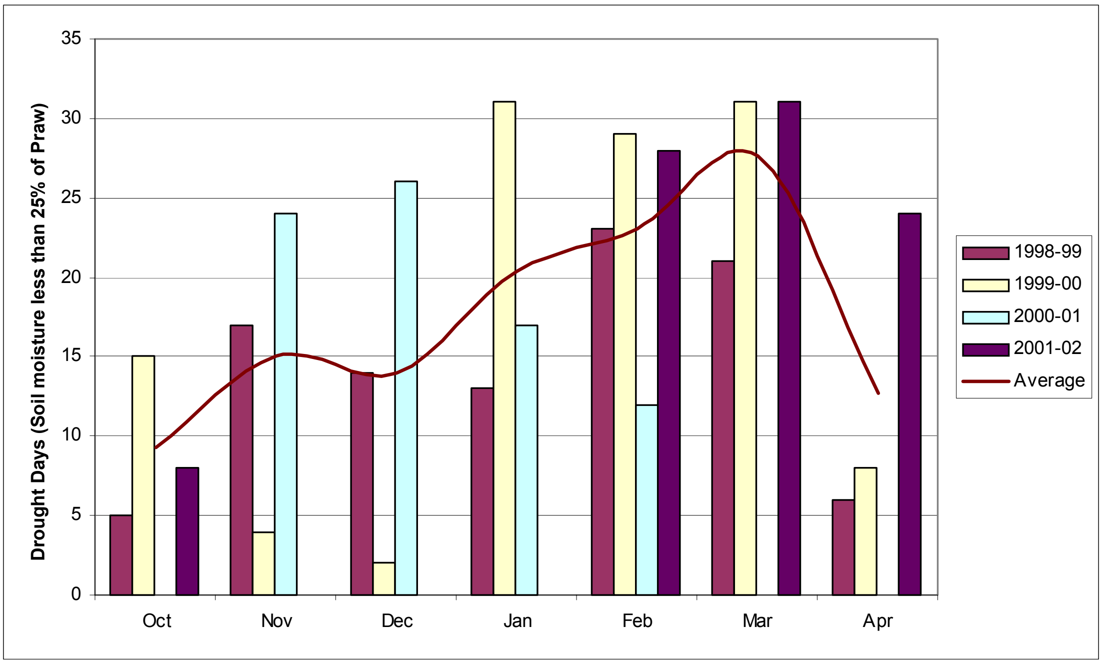


Figure I-2: Drought days (days/month) at Reporoa

Appendix J: Assessment of Farm Application Efficiency

The assessment of application efficiency in this study is based on empirical calculation. The approach is to utilise information on system type and design along with survey information on system operation and management to determine a reasonable assessment of likely efficiencies during periods of peak irrigation demand. It is in essence an estimate of the likely upper limit of efficiency, and does not take into consideration inefficiencies associated with system management over the irrigation season.

The application efficiency for systems and farms was calculated from application uniformity and irrigation management as listed below:

i) Application uniformity - determined as coefficient of uniformity (CU) from the following elements:

(a) Irrigation method

- Long-lateral system - coefficient of uniformity for the sprinkler type and sprinkler spacing was determined (using manufacturer distribution uniformity software (Nelson & Naan)) from sprinkler spacing based on percentage of overlap (over two or more irrigation cycles). While these have a nominal return period of 5 or 6 days, the actual return period allowing for sprinkler overlap is typically 8 or 9 days.
- K-lines - coefficient of uniformity based on sprinkler and lateral spacings for the sprinkler model, nozzle diameter and operating pressure, using manufacturer distribution uniformity software.
- Centre pivot - the pivot supply companies were unable to provide information on pivot uniformity for the specific system in the survey. However, information was available for similar systems, which show CU values of greater than 80%. The value of 85% was therefore adopted for this study.
- Travelling gun irrigator - a nominal CU value of 70% was adopted for the gun based on gun nozzle diameter and operating pressures.

(b) Wind affects

The impact of wind on sprinklers and spray gun application uniformity is dependent on speed and direction. However, generally as speed increases spacing between sprinkler and runs needs to be reduced to maintain uniformity. The frequency distribution of wind speed is a factor in selection of sprinkler type and spacing. Wind speeds recorded at the EW site at the McGillveray property near Reporoa, appear to be exceptionally low, with an average speed of less than one metre per second during the irrigation seasons between 1998-2002. By contrast average wind speed at Taupo, approximately 30 kilometres to the south, over the same period was more than 3 m/sec. There is no clear explanation for the difference between the two locations, one possibility is the sheltered nature of the Reporoa site, which may produce lower than typical values for the district.

The Taupo data is probably more representative of wind speed in the south Waikato, then wind speed will be a factor in system design and operation. Figure J-1 below is a plot of the cumulative wind speed (as mean month values) at Taupo over the irrigation seasons between 1998-2002, it shows that wind speed was more than 3 m/sec for about 50% of the time and more than 6 m/sec for 10% of the time. The implication for irrigation system design, is that for long-lateral and K-lines, sprinkler spacing should be reduced from still air spacing by at least 10%, and for travelling gun irrigators run spacing by about 30-35%.

Appendix J: Assessment of Farm Application Efficiency

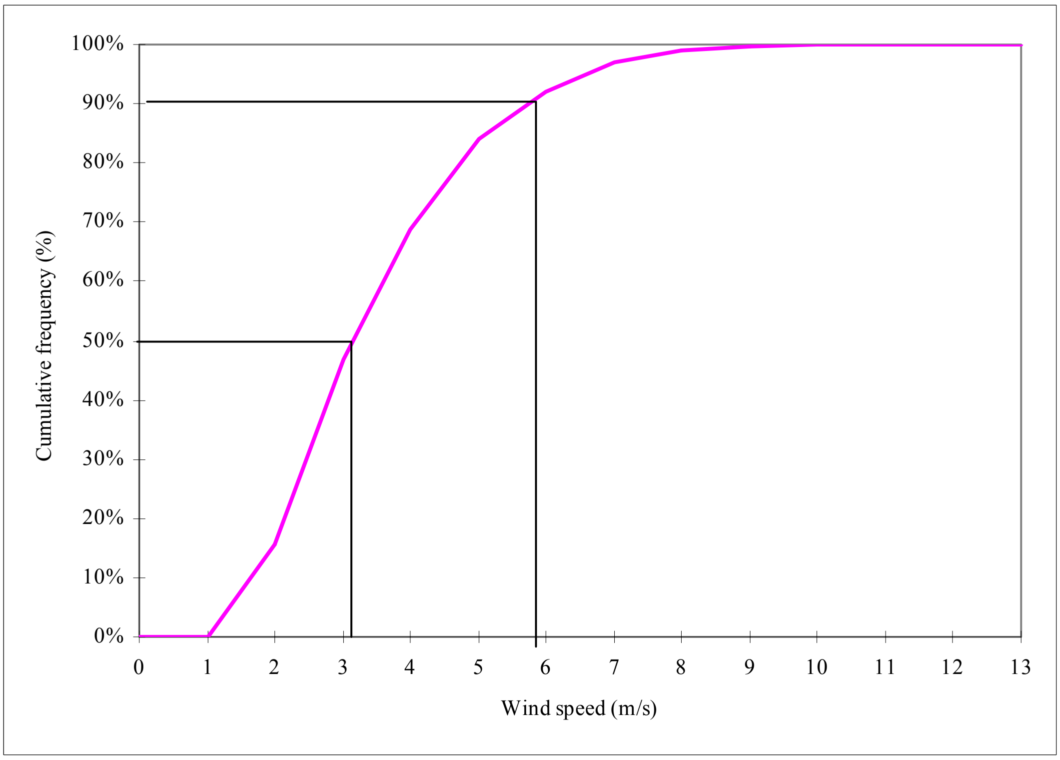


Figure J-1: Cumulative wind speed (%) during irrigation seasons (1998-2002) at Taupo

There is limited information on the specific information of the affects of wind on uniformity of system found in Reporoa. Work elsewhere shows that for sprinklers that CU decreased by more than 5% with an increase in wind speed of 1 m/s (3.6 km/hr). For this study the following relationships impacts of wind on CUs for the system has been assumed:

- Long-lateral and K-lines CU values decrease by 5%
- Cente-pivot CU values decrease by 5%
- Travelling gun irrigators CU values decrease by 10%

(c) Variations in operating pressure

Variations in operating pressure due to on-farm elevation difference were assessed based on field observation and information provide by the farmer and irrigation company. Elevation difference were more than 20 metres on several farms, particularly those drawing water from the Waikato River.

ii) Irrigation management - based on:

- Return interval (days)
- Application depth (mm/application)
- Design irrigation demand (mm/d) (a net value of 4.85 mm/d (equivalent to a gross value of 5.7 mm/d at a CU value of 70%)

Appendix J: Assessment of Farm Application Efficiency

Table J-1 lists a summary of the irrigation management parameters, return interval and duration, adopted for the systems and farms. As noted above for the long-lateral systems the nominal return period is usually 6 days, but in reality is 8 to 9 days once overlap between cycle is considered. Irrigation duration varied between systems and farms. Most of the long-lateral and K-line systems are designed to operate on a 12 hour day, typically 7:00pm to 7:00am to utilise night rate electricity charges (which are up to 7c/kWh lower than day rates). The centre pivots were operated on a 24 hour basis during periods of peak demand. While the travelling irrigators, were operated on 8 or 12 hours per run basis, with 2 or 3 runs per day during peak demand.

Table J-1 Summary of Irrigation Management

Farm No.	System(s)	Return interval (d)	Duration (hrs)	Application depth (mm)
1	Long-lateral	8	12	40
2	Long-lateral	8	12	36
3	Long-lateral	8	12	48
4	Long-lateral	7	8	23
5	K-lines	6	12	27
6	K-lines	7	12	34
7	Centre-pivots (2)	1-2	24	6-12
"	Easi-rain	6	12	34
"	Fixed Sprinkler	1	3	6
8	Centre-pivots	8	12	63
"	Long-lateral	2	17	10
9	Centre-pivot	1	24	4
"	Travelling gun	5-6	8	26
10	Travelling gun	7	8	34
11	Travelling gun	7	8	33
12	Travelling gun	14	10	51

Table J-2 presents a summary of the analysis of the system and farm application efficiencies. System efficiency is described in terms of CU and AE with the later term indicating the efficiency when mean application depth is matched to pre-irrigation soil water deficit. The management AE is an efficiency factor that takes into consideration return interval and application depth, with values of less than 100% indicating that the application depth is greater than the soil moisture deficit, and values greater than 100% that under-irrigation is occurring. Overall farm AE is a combination of the system and management AE components, and for farms with more than one system weighted on an area basis.

Appendix J: Assessment of Farm Application Efficiency

Table J-2 Summary of Farm Application Efficiencies

Farm No.	System(s)	System Efficiency		Management AE(%)	Farm AE (%)
		CU	AE (%)		
1	Long-lateral	57	79	>100	82
2	Long-lateral	62	81	>100	>100
3	Long-lateral	62	81	99	80
4	Long-lateral	67	84	>100	>100
5	K-lines	50	75	>100	>100
6	K-lines	63	82	>100	>100
7	Centre-pivots	85	90	>100	96
"	Easi-rain	57	79	>100	
"	Fixed Sprinkler	55	78	>100	
8	Centre-pivots	85	90	100	86
"	Long-lateral	60	80	77	
9	Centre-pivot	85	90	>100	>100
"	Travelling gun	55	78	>100	
10	Travelling gun	60	80	>100	>100
11	Travelling gun	60	80	>100	>100
12	Travelling gun	55	78	>100	>100

Appendix K: Seasonal Water Use Efficiency

The seasonal water use efficiency was evaluated by two methods:

i) Water use records: where there were sufficient records of water use from EW records water use efficiency was calculated on an annual basis.

ii) Electricity consumption: with the consent of the farm owners records of monthly electricity consumption were requested from the electricity supply company, Trustpower. These records formed the basis for the estimation of annual water use. The analysis is based on system duty, flow and pump motor rating(s). In some cases allowance were made for non-pumping demand such as electricity supply to milking sheds.

Seasonal Water Demand

As the basis for evaluation of seasonal water demand annual irrigation demand for each farm was calculated from the predicted irrigation demand from the soil water balance model. The calculated demand is the gross annual demand inclusive of an assessment application uniformity (CU) of 70%. Table K-1 lists a summary of annual irrigation demand for the period 1998-2002.

Table K-1: Annual Irrigation Demand

Farm No	Annual Irrigation Demand (m^3/yr)				
	1997-98	1998-99	1999-00	2000-01	2001-02
1				116,575	188,118
2				206,640	206,640
3			223440	143,640	168,840
4	568,960	568,960	497,840	320,040	320,040
5			392,000	252,000	252,000
6				151,200	151,200
7				476,280	476,280
8				161,280	161,280
9				352,800	352,800
10				302,400	302,400
11	331,520	331,520	290,080	186,480	186,480
12	98,000	98,000	84,000	78,400	78,400

Table K-2 presents a summary of annual water use efficiency, based on water use records, for the period 1997-2002. Apart from one record, all other records show efficiencies greater than 100% indicating under recording of water use, possible due to incomplete meter records and/or under irrigation due to the limitation of system capacity.

Appendix K: Seasonal Water Use Efficiency

Table K-2: Water Use Efficiency Based on Water Use Records

Farm No	Water Use Efficiency (%)				
	1997-98	1998-99	1999-00	2000-01	2001-02
1				NA	NA
2				NA	NA
3			NA	84	123
4	NA	NA	NA	NA	NA
5				NA	NA
6				132	123
7				NA	112
8				NA	NA
9			NA	NA	NA
10				NA	NA
11	130	124	172	116	NA
12	NA	NA	NA	NA	NA

Table K-3: Water Use Efficiency Based on Electricity Consumption Records

Farm No	Water Use Efficiency (%)				
	1997-98	1998-99	1999-00	2000-01	2001-02
1				NA	37
2				74	107
3			NA	NA	-
4	NA	NA	119	106	177
5				NA	-
6				125	127
7				NA	-
8				NA	104
9			87	106	114
10				NA	NA
11	116	103	74	75	94
12	NA	NA	192	248	121

Appendix L: Summary of Irrigation Costs for Study Farms

Information on irrigation costs was gained directly from farmers during the farm survey, and for operating costs from estimate of inputs for power, labour and maintenance. The following tables and text present a summary of this information and analysis. Table L-1 presents a summary of total capital costs and capital costs per unit area for the study farms.

Table L-1: Summary of Capital Costs

Farm No	Irrigation method(s)	Capital	Area (ha)	$/ha
1	Long-lateral	190,000	75	2,533
2	Long-lateral	202,000	82	2,463
3	Long-lateral	316,000	114	2,772
4	Long-lateral	445,000	125	3,560
5	K-line	345,000	100	3,450
6	K-line	120,000	60	2,000
7	Pivots, K-line, Sprinkler	1,000,000	189	5,291
8	Pivot, Long-lateral	280,000	64	4,375
9	Pivot, Travelling Guns	na	140	-
10	Travelling Gun	na	24	-
11	Travelling Gun	82,300	40	2,058
12	Travelling Gun	150,000	74	2,027

Table L-2 presents a summary of reported operating costs (power and maintenance) and labour requirements for the study farms.

Table L-2: Summary of operating costs

Farm No	Irrigation method(s)	Operating cost ($)	Maintenance ($)	Labour requirement (hr/d)
1	Long-lateral	?	?	1:30
2	Long-lateral	$100/day	?	?
3	Long-lateral	$12,000/yr	300/yr	2:30
4	Long-lateral	?	?	3:00 - 4:00
5	K-line	?	?	4:30
6	K-line	?	?	?
7	Pivots, K-line, Sprinkler	?	?	?
8	Pivot, Long-lateral	$90/day	?	?
9	Pivot, Travelling Guns	?	?	?
10	Travelling Gun	?	?	?
11	Travelling Gun	$3,700/yr	?	1:30
12	Travelling Gun	?	?	1:30 - 2:00

Appendix M: Summary of Farm Milk Solids Production

The following series of tables present summaries of farm productivity, stocking rate and productivity per cow and unit area over the past 4 seasons (1999-2003). In some cases records were not available for all seasons. The production figures for farms 9 and 10 are combined as the farms are run jointly.

Table M-1 presents the seasonal farm production values (kgMS). Note for the 2002-03 season values were taken in the period March-April, therefore prior to completion of the season.

Table M-1: Summary of milk solids production (kgMS) per farm per season

Farm No.	2002-03	2001-02	2000-01	1999-00
1	90,000	79,057	65,967	55,485
2	140,000	130,000	120,000	
3	201,000	181,000	125,000	103,000
4	180,000	150,000	150,000	150,000
5	90,000	99,000	100,000	
6	72,000	69,000	58,000	51,000
7	440,000	397,000	270,000	240,000
8	67,500	80,500	82,800	70,000
9	370,000	317,000	320,000	297,000
10				
11	57,000	54,342	56,828	52,860
12	113,000	105,000	94,000	

Table M-2 listing best estimates of number of milking cows milked during the season. Note that the figures do not include young or dry stock numbers, which on some farms where, carried on-farm and on other carried off-farm.

Table M-2: Summary of milking cows (cows milked for the season)

Farm No.	2002-03	2001-02	2000-01	1999-00
1	240	220	210	180
2	350	350	350	
3	500	485	350	
4	510	560	580	
5	340	295		
6	200	200	200	180
7	1,544	1,327	1,000	1,000
8	290	273	254	250
9	1,000	900	850	
10				
11	160	160	160	160
12	332	303	300	

Appendix M: Summary of Farm Milk Solids Production

Table M-3: Summary of stocking rate (milking cows per ha)

Farm No.	2002-03	2001-02	2000-01	1999-00
1	3.2	2.9	2.8	2.4
2	2.7	2.7	2.7	
3	3.0	2.9	2.1	
4	4.1	4.5	4.6	
5	3.4	3.0		
6	3.3	3.3	3.3	3.0
7	4.1	3.5	2.7	2.7
8	3.7	3.5	3.3	3.2
9	2.7	2.4	2.3	
10				
11	2.2	2.2	2.2	2.2
12	3.6	3.3	3.3	

Table M-4: Summary of milk solids production per unit area (kgMS/ha) (effective area)

Farm No.	2002-03	2001-02	2000-01	1999-00
1	1,200	1,054	880	740
2	1,061	985	909	
3	1,189	1,071	740	609
4	1,440	1,200	1,200	1,200
5	900	990	1,000	
6	1,200	1,150	967	850
7	1,173	1,059	720	640
8	865	1,032	1,062	897
9	1,000	857	865	803
10				
11	770	734	768	714
12	1,228	1,141	1,022	

Table M-5: Summary of milk solids production per cow (kgMS/cow)

Farm No.	2002-03	2001-02	2000-01	1999-00
1	375	359	314	308
2	400	371	343	
3	402	373	357	
4	353	268	259	
5	265	336		
6	360	345	290	283
7	285	299	270	240
8	233	295	326	280
9	370	352	376	
10				
11	356	340	355	330
12	340	347	313	

Appendix N: Summary of Financial Model - Assumptions and Parameters

The approach to the evaluation of the analysis of the financial costs and benefits of irrigation in the Reporoa basin is based on a generic farm model. The model is based on based on typical stocking rates, production levels and farm expenses in the south Waikato. It has were relevant taken into consideration information from the study farms, particularly information related to the change in stocking rates and per cow production following the introduction of irrigation (Appendix M). The model is intended to provide an indication of the comparative costs and benefits irrigation on farm productivity and returns. It is should be borne in mind that it is a relatively simple approach, based on generic values for farm costs and returns.

The model is based on the following assumptions and parameters:

i) A 'base case' farm is used to establish costs and returns for a typical non-irrigated farm; the stocking rate (2.8 cows) and production level (300 kgMS/cow) are consistent with typical levels in the south Waikato.

ii) A pasture production response of 4,200 kgDM/ha is assumed as the average annual response to irrigation. This is level of production is derived from the simulation of pasture yield over the period 1997-2002 (Appendix O). While this a relative time series production based on local information this would appear to be a relatively conservative estimate.

iii) Pasture production benefits are allocated according to the following criteria:
- 45% of the yield is conserved as supplementary feed for winter consumption, this contributes to the total farm feed budget and supplement for off-farm contributions either as direct imports or as off-farm grazing. The marginal benefit of the supplementary is cost at a rate of $0.10 per kgDM.
- 33% of the yield is converted to an increase in stocking rates at conversion rate of 3,900 kgDM/cow (DM consumption during the milking season), typically this is an increase in stocking rate of 0.4 cows/ha.
- 22% of the yield is converted to an increase in per cow milk solids production at the rate of 15 kgDM per kg MS, typically this is an increase of approximately 60kg MS/cow

Both the increase in stocking rates and per cow production are consistent with that reported for the study farms, and therefore reflect realistic responses to irrigation.

iv) Annual irrigation volume; the average annual irrigation demand is based on the average seasonal irrigation depth (360 mm equivalent to 3600 m^3/ha) for the period 1997-2002.

v) Irrigation costs are based on the following:
- System capital costs are based on typical values for the study farms, these values are higher than costs in other areas, the difference is due to the higher costs associated with remote water sources, pumping up to a kilometre to the farm takeoff.
- Annualised fixed costs are based on depreciation of above and below sections of the systems. The cost of above and below ground costs are system specific as are the depreciation rates, generally a higher proportion of K-lines and long-laterals are above ground than for centre pivot and travelling guns.

Appendix N: Summary of Financial Model - Assumptions and Parameters

- Operating costs are based on:
  - Energy costs comprising of both fixed and consumption charges as listed below:
    - Fixed charges (based on typical motor duty) based on information from Trustpower a unit rate of $30/ha was applied. This is typical of the fixed rate applying in the Reporoa area.
    - Consumption charges (kWh) are based on energy rate per system type (based on typical operating duty (m)) and average annual volume. A variety of charging schemes apply in the area, therefore an average unit rate charge of $0.12/kWh was adopted for the study.
  - Operation and maintenance costs are based on percentage (2-5%) of above system components.
  - Labour costs are based on average daily labour requirements (system specific) at an hour charge rate of $25.

vi) Farm expenses (non irrigation) are based on typical rates for dairy farms on the following criteria:
- Farm working expenses are based on a pro-rata rate per stock unit from the base case, less cost savings for supplementary feed benefits of irrigation.
- Non cash adjustments are based on pro-rata per stock units from the base case farm.

The model output are based on a unit area basis (ha), these include:

- Stocking rate
- Milk solids production
- Total income
- Farm working expenses
- Irrigation expenses
- Total expenses
- Cash surplus
- Irrigation marginal benefit ($/ha)
- Unit water cost ($/m^3)
- Unit water returns ($/m^3)

Appendix N: Summary of Financial Model - Assumptions and Parameters

Table N-1: Summary of financial analysis

Financial Analysis	Units	Base Case	K-lines	Long-lateral	Centre pivot	Travelling gun
Stocking Rate	cows/ha	2.8	3.2	3.2	3.2	3.2
MS Production	kgMS/cow	300	362	362	362	362
	kgMS/ha	840	1141	1141	1141	1141
MS Return	$/kgMS	3.70	3.70	3.70	3.70	3.70
Income:	$/cow	$/kgMS	$/ha	$/ha	$/ha	$/ha
Milk sales		3108	4222	4222	4222	4222
Net Stock Sales		272	306	306	306	306
Rebates and Other		22	25	25	25	25
Total Income		3402	4553	4553	4553	4553
Farm Working Expenses:	$/h					
Wages (excl. managers wage)		213	240	240	240	240
Animal Health		151	170	170	170	170
Breeding and Herd testing		81	92	92	92	92
Farm Dairy Expenses		56	63	63	63	63
Electricity		59	66	66	66	66
Pasture & Supplements		484	357	357	357	357
Fertiliser (Incl. Nitrogen)		409	461	461	461	461
Freight		22	25	25	25	25
Weed and Pest		28	32	32	32	32
Repairs & Maintenance		260	293	293	293	293
Vehicle Expenses		143	161	161	161	161
Standing Charges		230	259	259	259	259
Administration		90	101	101	101	101
Other		17	19	19	19	19
Total Farm Working Expenses:		2243	2338	2338	2338	2338
Irrigation Expenses:						
Irrigation Capital Cost	$/ha		3000	3000	4500	2500
Irrigation Fixed Costs						
Above %			75	70	60	75
Above Depn %			10	10	7.5	10
Below %			25	30	40	25
Below Depn %			5	5	5	5
Total annual fixed costs			263	255	293	219
Irrigation Operating Costs						
Operating head	m		55	60	65	90
Annual energy demand	kW		917	1000	1083	1500
Power charges	$/yr		0.12	0.12	0.12	0.12
Power fixed	$/yr		30	30	30	30
Power costs			140	150	160	210
O & M %	$/yr		5	5	2	5
O & M costs	5		113	105	54	94
Labour rating	hr/d/ha		0.040	0.025	0.010	0.030
Irrigation days per year	days		139	139	69	76
Labour rate	$/hr		25	25	25	25
Labour cost	$/yr		139	87	17	57
Total annual operating costs			391	342	231	361
Irrigation Expenses	$/yr	0	654	597	524	579

Appendix N: Summary of Financial Model - Assumptions and Parameters

Table 2 continued

Financial Analysis	Units	Base Case	K-lines	Long-lateral	Centre pivot	Travelling gun
Total Expenses		2243	2992	2935	2862	2918
Cash Surplus	414	1159	1561	1618	1691	1635
Non cash Adjustments:						
Change in Stock Numbers	63	176	199	199	199	199
Less Run-off Adjustment	17	48	54	54	54	54
Less Labour Adjustment	164	459	517	517	517	517
Less Depreciation	92	258	290	290	290	290
Total Adjustments:	**-210**	**-588**	**-663**	**-663**	**-663**	**-663**
Economic Farm Surplus:	**204**	**571**	**898**	**955**	**1028**	**973**
Marginal Benefits ($/ha)			**327**	**384**	**457**	**401**
Return on investment (%)			10.9	12.8	10.2	16.1
Water cost	$/m3		0.18	0.17	0.15	0.16
Capital cost	$/m3		0.07	0.07	0.08	0.06
Operating cost	$/m3		0.11	0.09	0.06	0.10
Power cost	$/m3		0.04	0.04	0.04	0.06
Non Irrigation cost	$/m3					
Gross returns	$/m3		0.32	0.32	0.32	0.32
Net returns	$/m3		0.09	0.11	0.13	0.11
Cost/kgDM			0.16	0.14	0.12	0.14

- Pasture and Supplements, includes hay, silage, meal, cropping, pasture renovation, grazing and contractor costs.
- Change in stock numbers from Dexcel Farm Fact No.7-3.
- Run-off adjustment is $140/cow, with a minimum of $30,800, for the first farmer and family labour unit plus the percentage of any additional farmer and family labour units multiplied by $25,000.
- If the farm owner works full time on the farm then no adjustment to the EFS wages expense is needed, ie: all the wages paid by the farm in the farm accounts are included in the wages expense. If the farm owner employs a manager to run the farm, the farm manager's wage is excluded from the wages expense for calculating EFS.

Appendix O: Pasture Production Parameters and Results

The pasture yield response to irrigation (Ya) is based on the calculation of the impact of period of soil water stress on potential production (Ymax). For the purposes of this study, the period of soil moisture stress was based on the ratio of actual to potential evapotranspiration (AET/PET). The yield response was calculated on a daily basis using the following equation:

$$Ya = \left(1 - \left(1 - \frac{ASM}{ASM_{\max}}\right)\right) Y_{\max}$$

Where:

Ya	is the yield response (potential yield response to irrigation)
ASM/ASM_{max}	is the ratio of actual soil moisture (derived from the water balance model) to maximum soil moisture (ASM_{max}) in this case Praw
Y_{max}	is the potential pasture production under irrigation (kgDM/d)

The table below lists the Ymax values (kgDM/day) adopted for this study. These values were derived from research in the district comparing irrigated and non-irrigated pasture during the 2000-01 season. The total annual for irrigated pasture is approximately 17,400 kgDM/ha/yr. This is a conservative estimate for pasture production as production in excess of 18,000 kgDM/ha have been recorded in the district, but is intended to provide reasonable working estimate, taking into consideration the potential impact of non-irrigation factors such as soil temperature and soil fertility levels.

Table O-1: Monthly Pasture Production Parameters Adopted in Pasture Response Model (kgDM/ha/d)

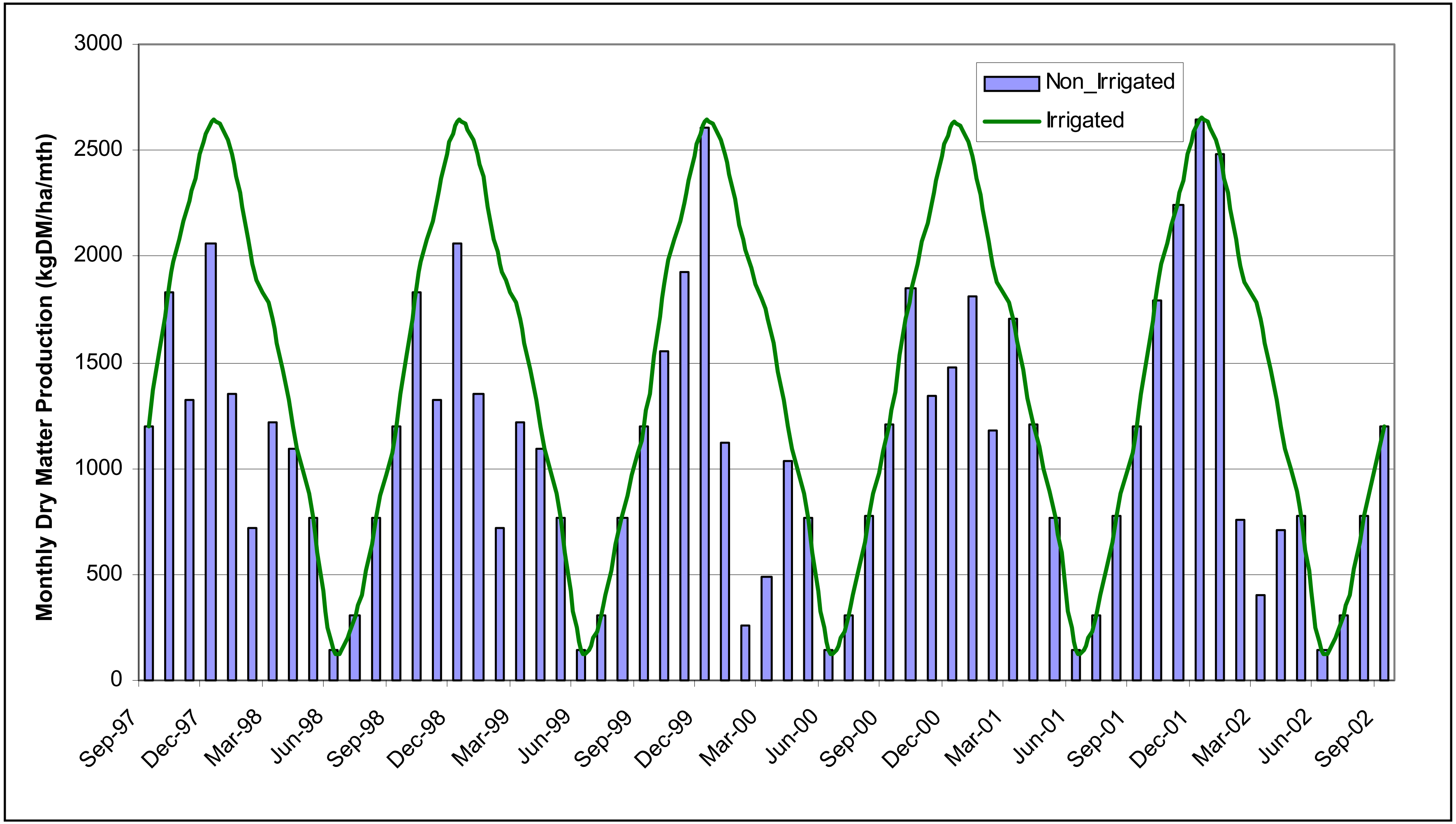
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
KgDM/ha/d	80	70	55	40	25	5	10	25	40	60	75	85

Table O-2: Pasture Production Response (kgDM/ha/mth) to Irrigation - Sept. 1997 - Jun. 2002

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
1998-99	0	0	0	36	933	575	1,125	1,246	489	104	0	0	4,508
1999-00	0	0	0	311	323	27	1,362	1,774	1,215	167	0	0	5,179
2000-01	0	0	0	3	912	1,154	654	784	0	0	0	0	3,508
2001-02	0	0	0	59	0	0	0	1,197	1,303	490	0	0	3,048
Mean	0	0	0	102	542	439	785	1,250	752	190	0	0	4,061
Std Dev	0	0	0	141	459	545	601	406	620	211	0	0	963
Max	0	0	0	311	933	1,154	1,362	1,774	1,303	490	0	0	5,179
Min	0	0	0	3	0	0	0	784	0	0	0	0	3,048

Appendix O: Pasture Production Parameters and Results

Figure 1: Comparison of Pasture Yield Response for Non-Irrigated and Irrigated Options for the Period Sept. 1997 to Sept 2002



Appendix P: Relationship between system uniformity and pasture production

The evaluation of the relationship between system uniformity and pasture production is based on the following assumptions and criteria:

- The pasture production function is based on the average monthly yields (Appendix) and the daily soil balance over the period Sept. 1997 to Aug. 2002.
- At soil moisture levels less than 50% of Praw (36mm) production decreases linearly
- The relationship between production and system uniformity is based on:
  - A normal distribution of application uniformity
  - An application depth of 36 mm per application
  - For 50% of the irrigated area application depth is greater than 36 mm (based on normal distribution).
  - For 25% of the irrigated area application depth is the mean of the depth of one standard deviation (Sn) calculated with Equation (1) (Benami et al, 1983)

$$Sn = \frac{100\,\bar{x} - Cu\,\bar{x}}{80}$$

where:

Sn = Standard deviation
$\bar{x}$ = mean application depth
Cu = system coefficient of uniformity

  - For 25% of the irrigated area application depth is the mean of the depth of two standard deviations
  - Annual pasture production is the sum three above application depths and irrigated areas.

The figure below shows the relationship between system uniformity (CU) and annual pasture production based on average annual production over the period Sept. 1997 to Aug. 2002. This relationship forms the based for the evaluation of the costs and benefits of improvements in on-farm irrigation efficiency.

An improvement in application uniformity from a CU of 60% to 80% will increase dry matter from production by approximately 500 kgDM/ha or the equivalent of 25 kgDM/ha per percent improvement in CU.

Appendix P: Relationship between system uniformity and pasture production