Irrigation Efficiency Enhancement – Stage 1

PREPARED FOR LANDWISE HAWKE'S BAY

Prepared by Ian McIndoe

Report No 4452/16a

March 2002

LINCOLN ENVIRONMENTAL
A division of Lincoln Ventures Ltd

TABLE OF CONTENTS

Page

Page

List of Tables:

EXECUTIVE SUMMARY

LandWISE Hawke's Bay is a Landcare group that is actively addressing a wide range of farming issues in Hawke's Bay. LandWISE Hawke's Bay initiated this project to audit a range of irrigation systems to establish benchmark performance levels for the standard of irrigation design in the district.

The objective of the study was, for fifteen irrigated properties covering a range of irrigation systems, enterprise and soil types, to determine:

- Parameters for determining irrigation design indicators;
- System design and operation limitations;
- Practical solutions for improving efficiency through better design,

The following performance indicators relating to design factors were used to assess irrigation system efficiency:

$$\textit{Application efficiency} = \frac{\textit{Water stored in the crop root zone (mm)}}{\textit{Total water applied to the soil (mm)}}$$

$$\textit{System capacity} = \frac{\textit{Irrigation system flow (}\ell\textit{/s averaged over 24 hours)}}{\textit{Area irrigated (ha)}}$$

$$\textit{Return interval} = \textit{Number of days between subsequent irrigations}$$

$$\textit{Hydraulic efficiency} = \frac{\textit{Pressure required at outlets of system (kPa)}}{\textit{Pressure supplied at system headworks (kPa)}}$$

$$\textit{Energy use efficiency} = \frac{\textit{Metered pump power (kW)}}{\textit{Pump flow rate (}m^3\textit{/h)}}$$

These indicators were calculated for each property and compared with expected values given best-design practice.

Each of the fifteen properties was visited by a consultant to obtain the necessary information and from that, design audits carried out. The audits determined appropriate irrigation system capacities, application depths, rates and return intervals for each property and compared those with actual system parameters.

Detailed hydraulic analysis was carried out to determine mainline pressure losses, pumping capacities and energy use for each property and these findings assessed against best design practice.

The standard of the design of the fifteen irrigation systems that were audited in this project was found to be extremely variable. Although all systems would benefit from minor changes, about half of the systems are designed well enough to provide the potential to be used efficiently. Of the others, significant improvements in water use efficiency, labour and energy efficiency could be achieved.

Six properties have adequate capacity to fully meet crop water demand, although three or four more could have sufficient capacity if operated for longer hours per day. On the remainder, capacity was limited and in some cases seriously limited. All irrigation systems had the ability to be operated so that the depth of water applied did not exceed the readily available soil moisture. On several properties, applying small depths of water would reduce overall system capacity because of the practical difficulties of keeping the systems operating for as many hours per day as possible. It is also likely that the design of some of the irrigation systems will cause application rates to exceed infiltration rates causing surface ponding and redistribution on occasions and reducing irrigation application efficiency.

The flexibility provided by the fixed irrigation systems allowed irrigation to occur as frequently as necessary, provided that they had sufficient system capacity. On most of the moveable systems, there are times when shorter return intervals than those currently used would be recommended for optimum production.

The systems with the highest application efficiency are the medium-length centre-pivots, linear move systems and drip and microsprinkler systems if they are operated to apply small depths of water on a regular basis. Slightly less efficient are rotary booms and possibly K Line and long line systems. The systems with the lowest application efficiency are guns and high application rate booms, particularly when they are applying large fixed depths of water over longer return intervals as many of the audited systems are.

Pressure losses within the pipe systems varied widely, with most close to those expected for a well-designed system. In two cases, mainline friction losses were much higher than recommended for good practice. About half of the systems had headworks pressures significantly in excess of that required, usually caused by changes from high pressure guns to lower pressure systems without modifying pump characteristics. Sufficient pressure was available to reasonably operate all systems at the design pressure.

In half of the audited systems, significant reductions in energy use could be achieved by selecting a pump that better matched the required duty or by improving the hydraulics of the system.

Overall, the study identified several issues related to irrigation design that are limiting system performance in Hawke's Bay.

There is a greater need to understand basic irrigation requirements and soil-plant water needs. Hawke's Bay soils can be particularly difficult and understanding soil properties is critical to good design.

Irrigation needs to be treated as an integral part of a farm business, not as an insurance policy. Farmers need to know that they should be designing farms around irrigation systems, not irrigation systems around farms.

Whenever possible, systems that have very uniform water application with the lowest practicable application rates should be used. This will ensure that the systems at least have the potential to make the best use of the available water.

Systems should be designed to a best-practice standard. Although there are no formal standards for the design of irrigation systems in New Zealand, information on design is now available – e.g. *The New Zealand Irrigation Manual* (MLG, 2001), *The Irrigation Guide* (FIMG, in press), and *Design Guidelines for Efficient Energy Use* (LE, in preparation). An independent irrigation design expert can help in this regard.

The expectation of the standard of detailed plans and specifications of irrigation systems as they are installed needs to be lifted. Without adequate records, it is difficult to carry out detailed audits or troubleshoot the system if things go wrong.

Farmers need to be made more aware of possible design problems, such as throttling pumps, excessive mainline friction loss and excessive application rates for example.

The issues can be dealt with through farmer and irrigation industry education. The ability to provide this training will be enhanced with the publication of the documents described above.

ACKNOWLEDGEMENTS

LandWISE Hawke's Bay is a landcare group that is actively addressing a wide range of farming issues in Hawke's Bay. It has an established network within the farming community and with staff from the Hawke's Bay Regional Council and research groups. LandWISE Hawke's Bay initiated this project to audit a range of irrigation systems to establish benchmark performance levels for irrigation in the district.

The project has been researched and written with the assistance of grants from The Agricultural and Marketing Research and Development Trust (AGMARDT), Hawke's Bay Regional Council and contributions from farmers, for which LandWise Hawke's Bay is very grateful. The AGMARDT grant was provided under the provisions of the Contestable Water Studies Fund, which was established jointly by AGMARDT and central government in 1999.

The technical analysis and reporting has been completed by Lincoln Environmental.

LandWISE Hawke's Bay has helped to facilitate the selection of farms on which the irrigation audits took place, and will help with the dissemination of results to the local farming community.

Dan Bloomer, Land Management Officer with the Hawke's Bay Regional Council, has managed the project, co-ordinated input from LandWISE members, and provided information on soils, climate and consents. He will facilitate the dissemination of project information through LandWISE and the Hawke's Bay Regional Council.

Farm visits and collection of data for farm audits have been carried out by Allen Kittow of Kittow AgHort Systems.

Data on crop water demand, soil water characteristics was provided by Dr Tony Daveron of Hydro Services Ltd, based on soil moisture monitoring carried out in the Hawke's Bay area.

1 INTRODUCTION

1.1 Background to Project

Pressure on water resources in Hawke's Bay is increasing as the area irrigated increases. It is generally accepted that improving the efficiency of irrigation will maximise the profitable use of limited water resources, particularly during periods when supply restrictions are in force. Improved efficiency will also reduce pumping costs. However, the current state of irrigation efficiency with respect to design and operational performance in Hawke's Bay is unknown. In order to improve irrigation efficiency in the region, an understanding of the reasons for inefficiency, if it exists, is needed.

Irrigation seminars were conducted in the Hawke's Bay region in January 2000, which raised farmers awareness of the potential limitations imposed on irrigation performance by poor design. Indications of poor hydraulic design that came to light in these seminars included operating pumps against partially closed gate valves, poor application uniformity, and irrigation return intervals that were too long for optimum crop production. A number of farmers expressed strong interest in having their irrigation systems audited.

Given this interest, a project that audited a representative cross section of irrigation systems in Hawke's Bay was considered to be an appropriate way of identifying irrigation design limitations and indicating a way forward for improving irrigation performance in the area.

1.2 Previous Work

The design of an irrigation system determines the potential efficiency and profitability of irrigation. Good irrigation design sets the platform for efficient operation. Poor design significantly limits what a farmer can do to maximise efficiency and profitability. The importance of design, as opposed to management, to irrigation efficiency and profitability has only recently been understood (Bright *et al.,* 1998).

Currently, there is only very limited field-based data available on the effects of system design on efficiency in New Zealand (the results of two case studies and a general study on design factors carried out in Canterbury (McIndoe & Carran, 1998; Borrie & McIndoe, 1998; Bright *et al.,* 1998). These studies identified irrigation design and management parameters that have the greatest influence on irrigation efficiency in general terms. The studies indicated that substantial water and cost savings could potentially be gained.

Without field data to benchmark current performance within the local Hawke's Bay situation, it would be impossible to assess how much irrigation efficiency could be improved. There was a need therefore, to check or benchmark the parameters for farms in Hawke's Bay.

1.3 Benefits

Irrigation system audits determine weaknesses, solutions, and potential benefits from improved water efficiency and reduced power consumption. This is of immediate benefit to those whose systems are analysed. Systematic analysis over irrigation system, crop, and soil types identifies any weaknesses in design methods, the resolution of which will be of benefit to all irrigation designers and farmers who wish to make the most effective use of a renewable, but limited resource, and reduce nutrient leaching.

By investigating the performance of the farm irrigation system as a whole - from water supply to water on the ground - this project complements the Ashburton Lyndhurst Irrigation Association study of the efficiency of different types of application systems. The Ashburton Lyndhurst Irrigation Association study takes a detailed look at a critical component of a farm irrigation system (application efficiency); whereas this study looks at how the design of the system, as a whole, affects water use efficiency and energy use.

1.4 Objectives

The project was a practical investigation of irrigation system design to assess the effectiveness and efficiency of irrigation systems in Hawke’s Bay, and quantify the limitations imposed on efficiency by poor design. The objective of the study was, for a range of irrigation systems, enterprise and soil types, to determine:

- System design and operation limitations;
- Parameters for determining irrigation performance indicators;
- Practical solutions for improving efficiency through better design.

The project aimed to identify typical design problems, limitations on performance, and offer solutions to enable LandWISE Hawke’s Bay to target problem areas to improve irrigation efficiency.

1.5 Outputs

This information will be transferred directly to the farmers whose irrigation systems will be audited, through their involvement in the project. It will also be provided to others in the region through the provision of results and recommendations to LandWISE, and to the irrigation community at large through the contribution of case study material for use in *The New Zealand Irrigation Manual* (Malvern Landcare, 2001).

2 IRRIGATION EFFICIENCY

As this project is focussed on improving the efficiency of irrigation systems, it is useful to review the current measures of irrigation efficiency and examine drivers of efficiency and methods for improving it.

2.1 Measures of Efficiency

There are thirty or more definitions of irrigation efficiency. Researchers such as Charles Burt, Bert Clemmens, David Painter and Peter Carran have all published definitions, as have many other people.

The measure of irrigation efficiency used depends on the area of interest. In general, the public's perception of irrigation efficiency is focussed mostly on water use, whereas farmer's perception relates more to production. For this reason, it is unrealistic to use one all-encompassing definition. Efficient irrigation depends on water use, energy use, labour, and capital investment and how those aspects relate to production and profitability of agricultural or horticultural enterprises.

2.2 Useful Definitions for this Project

Most of the common definitions are more relevant to irrigation management performance than to the standard of irrigation design. Give that the focus of this project is on design, performance indicators relating to design factors were selected. These are described below.

2.2.1 Application Efficiency

$$\textit{Application efficiency} = \frac{\textit{Water stored in the crop root zone (mm)}}{\textit{Total water applied to the soil (mm)}}$$

Although widely referred to, this definition requires soil moisture to be measured to determine water stored in the crop root zone, and at the same time water applied must be measured.

2.2.2 System Capacity

$$\textit{System capacity} = \frac{\textit{Irrigation system flow (}\ell\textit{/s averaged over 24 hours)}}{\textit{Area irrigated (ha)}}$$

This is commonly used as a benchmark to assess the ability of the irrigation system to meet evaporative demand.

2.2.3 Return Intervals

This is the maximum time interval between irrigation applications during the period of maximum water demand for each crop. Return interval depends on readily available soil moisture and average evapotranspiration (ET) over the return interval.

2.2.4 Hydraulic Efficiency

There is no single definition of hydraulic efficiency. However, for the purposes of this report, hydraulic efficiency is defined as follows.

$$\text{Hydraulic efficiency} = \frac{\text{Pressure required at outlets of system (kPa)}}{\text{Pressure supplied at system headworks}}$$

This gives an indication of how much pressure is lost between the delivery point and the point of discharge.

2.2.5 Energy Efficiency

$$\text{Energy use efficiency} = \frac{\text{Metered pump power (kW)}}{\text{Pump flow rate } (m^3/h)}$$

This definition provides a measure of how many units of electricity are used to pump one cubic metre (1000 litres) of water. It can also be calculated by dividing electricity use by volume of water pumped over a given time. Both definitions are equivalent.

2.2.6 Water Use Efficiency

$$\text{Water use efficiency} = \frac{\text{Production (kg/ha)}}{\text{Water used } (m^3/ha)}$$

Water use efficiency (volume of water used compared to crop production) gives an indication of how efficiently water is used to produce farm output. It must be used with care however as high values can indicate low production and very low water use, indicating perhaps that the crop has been under-watered.

2.3 Improving Design Standards

2.3.1 Methods of Improvement

There are two basic methods of improving the standard of irrigation design and irrigation efficiency. They are:

- ***Enforcement or regulation*** – requiring irrigation to be designed to a standard.
- ***Education*** – informing water users of the benefits of good design to encourage them to expect a high standard of design from irrigation equipment suppliers.

The difficulty with the first option is that there is no up-to-date or recognised standards for irrigation design in New Zealand. Measures are being put in place nationally to rectify this situation. Other difficulties are those related to enforcement and monitoring.

The second option is preferred. This project, along with other initiatives such as preparation of *The New Zealand Irrigation Manual* and *The South Canterbury Farmers Irrigation Manual* (McIndoe *et al.,* in preparation), is intended to inform users of the benefits of good irrigation design and management and providing information to help to achieve those benefits.

2.3.2 Drivers of Efficiency

In order to target improvements in irrigation efficiency, it is necessary to understand what drives improvements in irrigation efficiency on farm. The following are the key drivers of efficiency:

- Profitability/sustainability (reduced margins, lower commodity prices);
- National and international markets – contracts (quantity, quality), access to markets;
- Maintaining access to water (instream versus abstractive versus public/ amenity);
- Change of land ownership or enterprise;
- Environmental effects (on source and receiving waters – e.g. nitrates and pesticides);
- Environmental pressure (public perception);
- Cost of water ($\$/m^3$) (although marginal cost of water is very low).

All of the drivers are linked. Without profitability, irrigation is not sustainable. Without international market acceptance, there will be no product sales and no profit. Without meeting agreed environmental standards, there will be no water; therefore no profit.

Profit is the main incentive for efficient irrigation. Highest profits are obtained by using as little water as possible to obtain as much production as possible. Although using less water has environmental benefits such as reduced leaching and less effect on water sources, improvements in design efficiency need to, in some way, lead to higher, and at the very least, sustainable profits.

2.3.3 Typical Water Losses

In simple terms, the less water that can be pumped to provide potential crop yields, the more profitable irrigation will be. Knowing where losses are likely to occur is necessary to focus on areas for improvement. Typical losses in New Zealand pressurised irrigation systems are:

Loss component	**Range**	**Typical**
Leaking pipes	0-10%	0-1%
Evaporation in the air	0-10%	<3%
Wind blowing water off target area (drift)	0-20%	<5%
Interception (canopy losses)	0-10%	<5%
Surface runoff (spray irrigation)	0-10%	<2%
Uneven/excessive application depths and rates	5-80%	5-30%

Most of the focus has been on leaks in pipelines and spray irrigators irrigating in windy conditions, on hot days or spraying water onto roads, mainly because these factors are very visible. However, these losses are primarily operational losses and tend to be very small. From a design perspective, non-uniform water application resulting from poor water distribution uniformity or excessive application rates has the greatest effect on water application efficiency, far greater than evaporation, interception or leaking hoses. Systems that cannot apply depths of water appropriate to soil water holding capacities or apply water very evenly will be inefficient.

2.3.4 Uneven or Excessive Application

Uneven application means that for effective irrigation, significantly more water than the average deficit needs to be applied to replenish the deficit. Uniformity depends on several factors such as the design of the system, soil variations, crop size and rooting depth variations and wind. For a system with a uniformity coefficient[1] of 70% (typical of many irrigation systems in New Zealand), about 90 mm of water needs to be applied to replace a 50 mm soil moisture deficit over 90% of a field. Improving the uniformity to 90% means

---

[1] Uniformity coefficient = $100\left[1-\frac{\Sigma\left|X-\bar{x}\right|}{\Sigma X}\right]$

X = depth of water in equal spacings across field

$\bar{x}$ = average depth applied

Σ = sum of all measured depths

that only about 60 mm needs to be applied to achieve the same result. Uniformity, which is primarily a design issue, has a significant effect on water application efficiency.

The primary cause of excessive application rate on sprinkler irrigation systems is the design of the irrigation machine and the choice of application device. The problem is highlighted when large depths of water are applied. The effects of excessive application rates can be mitigated to some extent by applying small depths of water more frequently.

Excessive depths are caused by design limitations (systems that cannot easily be adjusted to apply small depths of water) and by poor irrigation management.

Although poor design contributes significantly to low water application efficiency, some farmers still over-irrigate with well-designed systems. The main reason for this is to minimise the risk of production losses. The marginal cost of applying extra water is low compared to the potential loss of production.

3 METHODOLOGY

The project required that the following steps be completed.

3.1 Selection of Farms

There are many different kinds of irrigation system types used in the Hawke's Bay area. These were to be subjectively assessed on the basis of the total area irrigated by each type and the total volume of water used. The five most significant types were to be selected for investigation, based on area irrigated and water use. The aim was to select three farms for each irrigation system type covering a range of crop and soil types – a total of 15 farms.

3.2 Field Data

Aided by a checklist developed by Lincoln Environmental, a qualified local consultant was to visit farms to obtain the information needed to complete an irrigation audit. This required significant farmer input to provide essential information on crops, soils, climate, management objectives, physical characteristics of the farm, irrigation management practices, and the hydraulic characteristics of the irrigation systems.

3.3 Best and Actual Design Parameters

This required determining water requirements, return intervals, application depths and rates from a best-practice point of view to set benchmarks for efficient design. As a result of the audits, actual values of water requirements, return intervals, application depths and rates could then be compared with best-practice values to identify potential limitations on irrigation performance.

3.4 Irrigation System Hydraulics

It was planned to use the IRRICAD™ irrigation design software, developed by Lincoln Environmental, to complete a detailed hydraulic analysis of each irrigation system: pump, reticulation system, and irrigators. This was needed to help identify potential performance limitations due to inappropriate pump selection, poorly arranged or incorrectly sized pipelines, or large pressure variations, for example.

3.5 Other Design Limitations

Application system uniformity, as well as pump and motor efficiency, well performance (where data permitted), maintenance programmes and downtime, and water quality were to be assessed as they are factors that potentially limit the efficiency of irrigation.

3.6 Irrigation Performance Indicators

Calculation of relevant irrigation performance indicators was required to serve as benchmarks for evaluating the performance of modified or new irrigation systems. Although indicators were developed and tested for MAF by Lincoln Environmental and Agriculture NZ, performance indicators related to irrigation design needed to be used for this project.

3.7 Recommendations

Recommended methods for overcoming the most significant problems on the audited irrigation systems, and steps others can take to prevent these limitations being repeated with new systems were to be made. Recommendations on how to avoid these limitations in new irrigation systems were to be developed for distribution through LandWISE and Regional Councils. They will also be incorporated in the future editions of *The New Zealand Irrigation Manual* (MLG, 2001).

4 SELECTED IRRIGATION SYSTEMS

An assessment of the range of different types of irrigation system used in the area was carried out by members of LandWISE Hawke's Bay and Hawke's Bay Regional Council. The aim was to select the five most significant types of irrigation in the district, based on area irrigated and water use, with three farms of each type selected for auditing – a total of fifteen farms. In selecting the farms, the aim was also to include a range of crop and soil types.

4.1 Selected Properties

The following farm properties were selected for auditing:

Table 1: Selected farm properties

Farm No	Enterprise type	Irrigation system type	Soil type
1	Mixed cropping Livestock	Lateral Hard hose gun	Poukawa peat loam Hastings sandy loam Hastings silt loam Hastings clay/silt loam
2	Mixed cropping Livestock	Hard hose gun	Hastings silt loam Pakipaki sandy loam
3	Mixed cropping Livestock	Hard hose gun Soft hose guns	Turamoe peat loam Ngatawara silt loam
4	Cropping	Towable linear	Hastings silt loam
5	Dairy farm	Centre-pivot - towable Rotary boom	Takapau silt loam over gravel Takapau silt loam (deep)
6	Dairy farm	Centre-pivot Low pressure boom Long line	Takapau silt loam Kaiapo silt loam
7	Process crops	Centre-pivot - towable	Hastings silt loam Okawa sandy loam Waipukurau sandy loam
8	Cropping	Hard hose gun with boom	Hastings silt loam
9	Cropping	Omme boom/gun	Hastings clay loam Kaipo clay loam
10	Beef/sheep/deer Peas	K Line	Karamu silt loam Ngatawara silt loam
11	Pipfruit orchard	Microsprinkler Microjet	Takapau silt loam
12	Vineyard	Dripline	Omahu sand on stony gravels
13	Beef/sheep/deer Cropping	Subsurface drip	Takapau silt loam over gravel
14	Dairy farm	Long line	Takapau silt loam over gravel
15	Organic vegetable	HH gun Microsprinkler Dripline	Pakowhai deep silt loam over gravel Te Awa silt loam over pumice Omahu sandy loam

The selection covered a wide range of crop types, irrigation system types and soil types.

4.2 Collection of Field Data

A questionnaire/audit checklist was sent to each farm. The completion of the questionnaire was required to provide essential information on crops, soils, climate, management objectives, physical characteristics of the farm, irrigation management practices, and the hydraulic characteristics of the irrigation system. After several weeks, a local farm consultant visited each farm and went through the questionnaire with the farmers concerned (or their representatives).

Hawke's Bay Regional Council staff also provided information on soils and climate. Information on water use and irrigation management for several of the properties was provided by Hydro Services Ltd, a company that had provided soil moisture measurements and irrigation scheduling services to farmers in Hawke's Bay.

Where necessary, further information was obtained by contacting the company that supplied the irrigation system.

4.3 Quality of Information Collected

The quality of information that could be collected for each property varied enormously. In some cases, detailed plans and specifications of irrigation systems were available. Usually farmers in these circumstances also had a good understanding of soil properties and crop parameters such as root depths.

In other cases, plans were not available and poor records were kept. In those situations, it was difficult to carry out detailed audits. The most common problem was lack of information on soil parameters, water holding capacities, crop root depths and management practices. It was also very difficult to obtain reliable information on pumps and wells.

5 BASIC DESIGN PARAMETERS

Given the scope of the project, it was not feasible to carry out a detailed irrigation demand study. The scope of the project was aimed to determine basic climatic and soil parameters and to find out if systems were designed to meet those parameters. Of particular interest were evapotranspiration (ET) rates, soil water holding capacities and allowable soil water deficits, system return intervals, application depths and application rates.

Rainfall, although an important part of irrigation management and seasonal water use, was not included in determining water requirements and basic design parameters. As Hawke's Bay is prone to periods of little or no effective rainfall for two to three weeks or longer, irrigation systems should have the capacity to meet demand over those periods. The demand in those periods is dominated by evapotranspirative demand, with rainfall having little influence.

5.1 Evapotranspiration

The ET values for Napier (D96591) are shown in Table 2. Although some properties are several kilometres from Napier, average ET values do not change significantly over a region, although values on particular days could vary. As this study is concerned with basic design rather than day-to-day management of irrigation systems, Napier ET values give an indication of the expected ET for the region.

Table 2: Evapotranspiration for Napier

Month	Mean daily ET (mm)	Mean monthly ET (mm)
September	2.1	63
October	3.2	99
November	4.2	127
December	4.7	145
January	4.8	148
February	4.1	116
March	3.0	93
April	1.9	56
TOTAL		**847**

As can be seen from the above table, average monthly ET peaks at about 4.8 mm in December and January. For shorter periods, it is reasonable to expect that ET would exceed 5 mm/d and perhaps reach 5.5 mm/d. Systems designed at less than 5 mm/d will therefore need to rely heavily on soil buffering if they are fully irrigating field and pasture crops during December and January.

5.2 Soil Parameters

The key soil–related parameters that must be considered when designing irrigation systems are water holding capacity in the root zone of the crop, the allowable soil moisture deficit, the ET daily rate that must be replenished by irrigation and the number of days between irrigation applications. The infiltration rate of the soil (i.e. the rate, measured in mm/h, that the soil can absorb water without visible ponding and runoff occurring) is also important.

Although generic values are often used for soil water holding capacities, in reality they depend on soil type and crop rooting depth at the time of maximum demand. This will generally be in January, although for some earlier maturing crops it could be in December.

The values listed in Table 3 were obtained from soil moisture measurement data provided by Hydro Services Ltd, based on soil moisture monitoring in the Hawke's Bay area. Note that some of the soil types such as Takapau silt loam do not release water readily (the allowable deficit), despite having moderate to high water holding capacities. Soil infiltration rate is not included in Table 3 because data was unavailable.

Table 3: Typical soil parameters

Crop type	**Soil type**	**Root depth (mm)**	**WHC in root zone (mm)**	**Allowable deficit (mm)**	**Design ET (mm)**	**Return interval (days)**
Potatoes	Pakowhai silt loam	400	82	29	5.5	5-6
Potatoes	Te Awa silt loam	400	83	37	5	7-8
Grapes	Omahu sandy loam	600	50-66	35-43	4	8-10
Grapes	Ngatawara sandy loam	600	123	80	4	20
Maize	Hastings silt loam	600	125	56	4.5	12
Potatoes	Hastings silt loam	400	88	31	5.5	5-6
Squash	Hastings silt loam	400	88	48	4.5	10-11
Peas	Hastings silt loam	400	92	46	4	11-12
Pasture	Takapau silt loam	400	86	30	5	6
Pasture	Takapau silt loam (deep)	400	92	32	5	6-7
Maize	Poukawa peat loam	600	138	48	4.5	10-11
Ryegrass seed	Hastings sandy loam	400	82	37	4	9-10
Fescue	Hastings silt loam	800	184	100	3.5	28-30
Peas	Poukawa peat loam	400	90	36	4	9
Sweet corn	Hastings clay/silt loam	600	130	58	3	19
Cereals	Hastings clay/silt loam	1000	190	104	2.5	40
Pasture	Hastings silt loam	400	90	40	4 - 5	8-10

Table 3 illustrates the huge variation in design parameters necessary to meet crop water requirements in Hawke's Bay. The shallow rooted crops on soils that do not readily release water should be irrigated on return intervals as low as 5-6 days.

6 DESIGN PARAMETERS OF AUDITED SYSTEMS

6.1 System Capacity

Table 4 summarises the required and actual system capacities for the audited properties.

Table 4: System capacities

Farm No	Enterprise type	Irrigation system type	Required system capacity (ℓ/s/ha) over 24 hours	Actual system capacity (ℓ/s/ha) over 24 hours	Operating hours per day	Actual system capacity (ℓ/s/ha)
1	Mixed cropping Livestock	Lateral Hard hose gun	0.42	0.35	22	0.32
2	Mixed cropping Livestock	Hard hose gun	0.46	0.65	15	0.41
3	Mixed cropping Livestock	Hard hose gun Soft hose gun	0.56	0.66	22	0.60
4	Cropping	Towable linear	0.54	0.53	23	0.51
5	Dairy farm	Centre-pivot towable Rotary boom	0.58	0.39	24	0.39
6	Dairy farm	Centre-pivot Low pressure boom Long line	0.58	0.51	17	0.46
7	Process crops	Centre-pivot towable	0.51	0.24	23.5	0.23
8	Cropping	Hard hose gun with boom	0.61	0.50	20	0.42
9	Cropping	Omme boom/gun	0.41	1.15	13	0.62
10	Beef/sheep/deer Peas	K Line	0.46	0.48	24	0.48
11	Pipfruit orchard	Microsprinkler Microjet	0.46	1.29	12	0.65
12	Vineyard	Dripline	0.46	0.66	24	0.27
13	Lucerne	Subsurface drip	0.67	1.18	14	0.39
14	Dairy farm	Long line	0.58	0.96	15	0.60
15	Vegetable	HH gun Microsprinkler Dripline	0.47	0.42	22	0.39

Required system capacity depends on the mix of crops irrigated and the stage of crop. For single enterprise systems such as dairy farms, required system capacity is that needed to adequately irrigate pasture in January. For multiple crop systems, required system capacity is the capacity needed to adequately irrigate crops in the month of peak demand. This can be December or January, depending on crop mix. Note that these values do not allow for areas with high water tables where upward movement of water could meet some of the crop water demand. In these cases, the required system capacities given in Table 4 could be higher than necessary in practice.

Actual system capacity is the capacity of the irrigation system as audited, based on 24 hours operation per day. As systems are not usually operated over 24 hours, the system capacity based on the actual number of hours of irrigation is also given.

6.2 Consent Requirements

Table 5 compares the peak flow rates and weekly volumes of water required for effective irrigation with peak rates and weekly volumes consented for take.

Table 5: Consent requirements

Farm No	Enterprise type	Area irrigated (ha)	Peak flow required (ℓ/s)	Consent flow allowed (ℓ/s)	Actual peak flow (ℓ/s)	Volume of water required (m^3/w)	Consent volume allowed (m^3/w)
1	Mixed cropping Livestock	233	108	75	75	50,000	37,800
2	Mixed cropping Livestock	35	26	20	23	9,700	10,100
3	Mixed cropping Livestock	60-100	80		64	44,000	10,100
4	Cropping	32	19	25	18	10,600	15,120
5	Dairy farm	311	186	152	160	109,000	91,929
6	Dairy farm	218	193	188.5	179	76,000	75,648
7	Process crops	134	71	55	32	42,000	44,144
8	Cropping	54	39	115	27	19,800	29,361
9	Cropping	16	12	35	18	3,900	2,437
10	Beef/sheep/deer Peas	44	21	22	21	12,300	13,305
11	Pipfruit orchard	68	63	69	69	19,000	31,232
12	Vineyard	23	11	45	10	6,500	4,500
13	Beef/sheep/deer Cropping	20	23	50	25	8,000	13,000
14	Dairy farm	138	128	140	141	48,000	51,000
15	Vegetable	118	85	61	53	30,000	32,500

6.3 Application Depths

The basic requirement with irrigating crops is to have the flexibility to apply varying depths of water according to the stage of crop and the soil type. This flexibility is required to prevent over-watering through all stages of crop development and to prevent stress during times of peak demand. Table 6 presents the range of application depths needed for efficient irrigation and compares those depths with the depths typically applied by the irrigation system.

Table 6: Application depths

Farm No	Enterprise type	Irrigation system type	Required depth range (mm)	Actual depth applied (mm)
1	Mixed cropping Livestock	Lateral Hard hose gun	36-105 41	17 40-50
2	Mixed cropping Livestock	Hard hose gun	24-75	35
3	Mixed cropping Livestock	Hard hose gun Soft hose guns	22-48 22-48	50 50
4	Cropping	Towable linear	31-56	20
5	Dairy farm	Centre-pivot - fixed - towable Rotary boom	30 30 32	16 35-40 33
6	Dairy farm	Centre-pivot Low pressure boom Long line	20-30 30-45 30-45	15 30-40 25-30
7	Process crops	Centre-pivot - towable	28-91	18
8	Cropping	Hard hose gun with boom	31-48	55
9	Cropping	Omme boom/gun	44-60	35
10	Beef/sheep/deer Peas	K Line	39-80	60
11	Pipfruit orchard	Microsprinkler Microjet	20	12
12	Grape vines	Dripline	43	3.6
13	Beef/sheep/deer Cropping	Subsurface drip	47	6+
14	Dairy farm	Long line	30	28-33
15	Organic vegetable	HH gun Microsprinkler Dripline	18-75 56 31-79	35-40 5+ 5+

6.4 Application Rate

The application rate of the range of irrigation systems and the infiltration rates of the irrigated soils are given in Table 7. Because soil infiltration rate depends on many factors such as depth of water applied, crop cover, slope, soil sealing characteristics, salinity and watering time, rates given in the table are, at best, estimates.

Table 7: Application and infiltration rates

Farm No	Irrigation system type	Application rate (mm/h)	Infiltration rate (mm/h)
1	Lateral Hard hose gun	43 8	10-15 10-15
2	Hard hose gun	9	10-20
3	Hard hose gun Soft hose guns	8 8	8-15
4	Towable linear	37	10-30
5	Centre-pivot - fixed - towable Rotary boom	up to 72 up to 95 12	15-40 10-30 10-20
6	Centre-pivot Low pressure boom Long Line	59 70-90 3	20-40 10-20 15-20
7	Centre-pivot - towable	up to 42	20-40
8	Hard hose gun with boom	44	10-20
9	Omme boom/gun	9	10-15
10	K Line	4	15-25
11	Microsprinkler Microjet	4 4	10-20 10-20
12	Dripline	NA	NA
13	Subsurface drip	NA	NA
14	Long line	4	10-20
15	HH gun Microsprinkler Dripline	8 3 NA	15-25

6.5 Return Interval

Return interval is important because it determines if the system is capable of watering the crop frequently enough to prevent crop stress. Table 8 compares the return interval required for effective irrigation with the actual return interval of the irrigation systems on each property.

Table 8: Irrigation return intervals

Farm No	Enterprise type	Irrigation system type	Required return interval (days)	Actual return interval (days)
1	Mixed cropping Livestock	Lateral Hard hose gun	10-46 14	6 15
2	Mixed cropping Livestock	Hard hose gun	5-25	10
3	Mixed cropping Livestock	Hard hose gun Soft hose guns	5-10 5-10	15 15
4	Cropping	Towable linear	6-14	15
5	Dairy farm	Centre-pivot - fixed - towable Rotary boom	6 6 6	3 8-10 7
6	Dairy farm	Centre-pivot Low pressure boom Long line	4-6 6-9 6-9	3 15 7
7	Process crops	Centre-pivot - towable	5-25	5
8	Cropping	Hard hose gun with boom	6-11	14
9	Cropping	Omme boom/gun	15	14
10	Beef/sheep/deer Peas	K Line	10-20	14
11	Pipfruit orchard	Microsprinkler Microjet	5	3
12	Vineyard	Dripline	11	1+
13	Beef/sheep/deer Cropping	Subsurface drip	9	1+
14	Dairy farm	Long line	6	6-7
15	Organic vegetable	HH gun Microsprinkler Dripline	5-19 16 7-23	14 2 1

6.6 Application Efficiency

Application efficiency is the ratio of volume of water stored in the root zone of crops and the total volume of water applied. It is important because it determines how much additional water above the average soil water deficit that needs to be applied to re-fill the soil profile over the majority of the irrigated area.

The major cause of loss of application efficiency is non-uniform watering. This non-uniform watering is due to the inherent watering pattern of the irrigator, wind, system pressure variations, surface ponding and excessive application depths.

Sprinkler distribution patterns are normally determined under controlled conditions because it is virtually impossible to obtain representative data in the field that can be used for general design. Many factors (such as wind direction and speed, nozzle pressures and flow rates, and sprinkler heights) influence results in the field, and wide ranges in values are almost always measured.

At the project concept stage, it was suggested that on-farm measurement of application uniformity be considered. Because of the number of variables involved, a single test on each farm would not have given representative results. A large number of tests would have been required to determine an average uniformity and expected range for each farm.

The approach adopted for this study was to use results from controlled conditions with the implication that high uniformity under these conditions would result in better performance in the field than would occur with systems with poor uniformity under controlled conditions.

Table 9 provides best estimates of application efficiencies for each irrigation type on each property, given the specific uses on the properties.

The source of data for the values given in Table 9 depended on the type of system and an assessment of the likely performance based on measured or published data. This included John *et al.* (1985), Naan Irrigation overlap data, Nelson Irrigation Corporation overlap data, Bright *et al.* (1998), McIndoe & Carran (1998), and Solomon (1988).

Table 9: Application efficiencies

Farm No	Enterprise type	Irrigation system type	Estimated application efficiency (%)
1	Mixed cropping Livestock	Lateral Hard hose gun	85-90 65-75
2	Mixed cropping Livestock	Hard hose gun	70-75
3	Mixed cropping Livestock	Hard hose gun Soft hose gun	65-75 65-75
4	Cropping	Towable linear	80-90
5	Dairy farm	Centre-pivot - fixed - towable Rotary boom	90-95 85-90 80-85
6	Dairy farm	Centre-pivot Low pressure boom Long line	90-95 70-75 85-90
7	Process crops	Centre-pivot – towable	85-90
8	Cropping	Hard hose gun with boom	80-85
9	Cropping	Omme boom/gun	75-80
10	Beef/sheep/deer Peas	K Line	80-90
11	Pipfruit orchard	Microsprinkler Microjet	85-90 80-85
12	Vineyard	Dripline	90-95
13	Beef/sheep/deer Cropping	Subsurface drip	90-95
14	Dairy farm	Long line	85-90
15	Organic vegetable	HH gun Microsprinkler Dripline	65-75 85-90 85-95

7 HYDRAULIC ANALYSIS

All hydraulic analysis was carried out using the IRRICAD™ irrigation design software.

7.1 Pressure Losses

Hydraulic loss gives an indication of how much pressure is lost between the start of the mainline at the system headworks (not including losses through system headworks) and the point of discharge, i.e. at the sprinkler nozzle. It depends on pipeline friction loss, elevation change, hose losses, static lift, hydrant losses and losses through any other component between the headworks and the outlets. This changes according to irrigation system type and layout.

To assess the hydraulic performance of each system, the hydraulic loss has been calculated as follows:

$$\text{Hydraulic loss} = \frac{100 \times (\text{headworks pressure} - \text{sprinkler pressure})}{\text{Headworks pressure}}$$

The optimum hydraulic losses, which are those that would be expected for a properly designed system, are also given.

The difference between actual loss and optimum loss gives an indication of the magnitude of improvements that could be made, given good design practice.

Table 10: Hydraulic losses

Farm No	Irrigation system type	Actual hydraulic loss (%)	Optimum hydraulic loss (%)
1	Lateral Hard hose gun	75-80	30-50 35-50
2	Hard hose gun	56	55-60
3	Hard hose gun Soft hose guns	36-57	35-50
4	Towable linear	23	20-40
5	Centre-pivot - fixed - towable Rotary boom	77 76 13	50-60 50-60 20-30
6	Centre-pivot Low pressure boom Long line	75-80 75-85 15-25	60-70 70-75 20-30
7	Centre-pivot - towable	41-80	40- 65
8	Hard hose gun with boom	69	65-70
9	Omme boom/gun	42	40-50
10	K Line	45-48	30-45
11	Microsprinkler Microjet	50-55	45-50

Farm No	Irrigation system type	Actual hydraulic loss (%)	Optimum hydraulic loss (%)
12	Dripline	56	50-60
13	Subsurface drip	71	65-75
14	Long line	59 76	55-60 70-75
15	HH gun Microsprinkler Dripline	52 64 89	50-60 30-40 50-60

7.2 Well Performance

An objective of the study was to assess well performance. Drawdown in a well is caused primarily by loss of head in the aquifer and loss of head in the well itself. The loss of head in the aquifer is related to aquifer transmissivity, which is a measure of how difficult it is to pull water through the aquifer. The loss of head in the well is called well loss and is related to well construction and development. Wells with high well loss can often be improved to reduce the total drawdown and increase pumping rates.

Well performance was qualitatively addressed in each of the individual reports and comment was made on well loss whenever possible. To quantitatively calculate well loss, comprehensive well tests such as step-drawdown tests or constant discharge tests using observation wells need to be carried out and the data analysed to calculate well losses.

Unfortunately, the data needed to properly assess well performance was not available for the wells on the properties included in the study. This was unexpected, given the importance of groundwater to the region. The test data was generally limited to a specific capacity test or a longer term constant discharge test without observation bores.

Table 11 provides a summary of well performance for each property.

Specific capacity (pumping rate divided by drawdown) provides an indication of overall well performance. High specific capacity wells are usually high performance wells. Low specific capacity wells are due to low transmissivity and/or high well loss. Where insufficient information is given, it is impossible to distinguish between high well loss and low transmissivity as both cause high drawdown.

As transmissivity data was rarely available, a qualitative assessment has been made based on the type of aquifer, its location and overall well performance.

Well loss has also been estimated based on the type of aquifer, location and overall performance. Where the flow drawdown relationship is linear, such as in unscreened wells drilled into limestone, well loss is usually very low and the wells considered to be efficient.

Table 11: Summary of well performance

Farm No	Water supply	Specific capacity (ℓ/s/ha)	Transmissivity (m^2/d)	Estimate of well loss
1	Well	20.0	High	Low
2	Well	Unknown	Unknown	Unknown
3	Wells	High	High	Unknown
4	Well	0.73	Low	Unknown
5	Wells	1.0	Low	Unknown
6	Wells	6-8	Average	Unknown
7	Well	1.2	213 (low)	Very low
8	Rivers/wells	N/A	N/A	N/A
9	Well	13.6	Very high	Unknown
10	Well	1.0	Low	Low
11	Well	Unknown	Unknown	Unknown
12	Well	5.5	Average	Unknown
13	Well	1.0	Low-medium	Low
14	River	N/A	N/A	N/A
15	Wells	50-75	Very high	Unknown

A wide range in well specific capacities was found. Well losses, where they could be assessed, were low. However, assessments could not be made on the majority of wells.

7.3 Pump/Headworks Operation

Table 12 summarises the pressure available immediately downstream of the headworks (at the beginning of the mainline), assuming that all valves are wide open (no throttling), and compares it with the required pressure.

The optimum pressure, given best design practice and assuming that the current method of irrigation is retained, is also given. This will be lower than the required pressure if further improvements can be made to the system, such as increasing pipe sizes or reducing friction loss in other ways.

The difference between the available headworks pressure and optimum headworks pressure gives an indication of the extent to which operating pressures could be reduced, given best design practice. A well-designed system is one where all three pressures are the same.

Table 12: Headworks pressures

Farm No	Irrigation system type	Available pressure (m)	Required pressure (m)	Optimum pressure (m)
1	Lateral Hard hose gun	63	51	41
2	Hard hose gun	90	90	88
3	Hard hose gun Soft hose guns	105	100-110	100-110
4	Towable linear	80	30	30
5	Centre-pivot - fixed - towable Rotary boom	80 80 35	43 41 40	38 40 40
6	Centre-pivot Low pressure boom Long line	45 45-56 45-56	30 40 45-56	30 40 50-55
7	Centre-pivot - towable	46	50	30-35
8	Hard hose gun with boom	96	96	96
9	Omme boom/gun	200-250	90	90
10	K Line	77	58	19
11	Microsprinkler Microjet	39-45	44	40
12	Dripline	37	25	25
13	Subsurface drip	40	40	40
14	Long line	69 117	74 119	68 110
15	HH gun Microsprinkler Dripline	110 110 110	105 57 31	105 57 31

7.4 Energy Efficiency

Power rating is used as an indicator of energy efficiency and has been calculated for all irrigation systems in the study. It provides a measure of how many units of electricity are used to pump one cubic metre (1000 litres) of water. In general, the lower the power rating, the better.

$$\text{Power rating} = \frac{\text{Metered pump power (kW)}}{\text{Pump flow rate (m}^3\text{/h)}}$$

The actual power rating, correct pump power rating, and optimum design power rating are presented in Table 13.

Actual power rating is the energy used per cubic metre of water pumped for the system as currently installed.

Correct pump power rating is the rating assuming that the pump can operate without throttling. Significant differences between actual and correct power ratings indicate either throttling or operating a pump at low efficiency.

Optimum design power rating is the power rating that should be able to be achieved, given best design practice. The difference between the actual power rating and the optimum design rating, multiplied by the number of cubic metres of water pumped in a season provides the kWh of energy that could be saved if best design practice had been employed.

Table 13: Power ratings

Farm No	Actual power rating (kWh/m^3)	Correct pump power rating (kWh/m^3)	Optimum design power rating (kWh/m^3)
1	0.28	0.28	0.20
2	0.45	0.42	0.35
3	0.52	0.51	0.50
4	0.52	0.32	0.35
5	0.59	0.47	0.46
6	0.17-0.23	0.17-0.20	0.15-0.20
7	0.30	0.28	0.20
8	0.37	0.37	0.37
9	0.96	0.43	0.45
10	0.52	0.45	0.45
11	0.21	0.21	0.20
12	0.22	0.20	0.20
13	0.36	0.36	0.34
14	0.34 0.60	0.34 0.60	0.33 0.56
15	0.58 0.46	0.58 0.46	0.25-0.58 0.25-0.46

8 DISCUSSION

8.1 Adherence to Basic Design Principles

8.1.1 Layout

One of the most basic irrigation design principles is, wherever possible, to design the farm around the irrigation system. This means moving fences, farm roads, perhaps buildings, cutting down trees, replanting (and irrigating) shelter belts, and so on to create a layout that allows optimal use of the irrigation system. Although some compromise is often needed, failure to follow this basic principle results in a system that is often more expensive to install, is harder to operate and maintain, more expensive to run and substandard in its performance.

The majority of the irrigation systems audited in this study appear to have been designed around the farm. Historically, this has occurred when irrigation was used as an insurance against drought rather than a necessary input into a farm business. Today, however, irrigation is almost always a necessary farm input, like fertiliser, and needs to be treated that way.

No doubt there are many reasons why most of the layouts are less than optimum. They may have been inherited from earlier generations or bought with the property. There will be reluctance to cut down trees that were planted many years ago. The systems may have originally been put in to get by in a previous drought. Using leased land rather than having outright ownership of the land creating the need for portable systems may also be a contributing factor.

8.1.2 Design Standards

Although some systems are well-designed, Hawke's Bay appears to have gone through a period where a disproportionate number of irrigation systems were designed poorly. With the limited number of designs audited, it is unclear as to whether that trend is continuing. However, given the current high demand for irrigation services nationally, a reduction in competition may mean that it is unlikely to improve in the near future.

The reasons for poor design are wide and varied.

Lack of professional design skills from irrigation supply companies has no doubt contributed. Although most of the irrigation designers now entering the industry have tertiary qualifications, there is no formal training available and "learning as you go" is common. This is evident from some of the systems audited. The fact that there are no useful design standards or guidelines in New Zealand does not help. Most of the systems information in the only design standard available (SANZ, 1973) is now inappropriate for current technology.

All of the responsibility for poor design should not be put on the irrigation suppliers/designers. Often a farmer's wish to put in a system as cheaply as possible over-rides good practice. Also, an unwillingness to make physical changes to farm layouts restricts what designers can do. Farmers understandably tend to over-stretch systems to get as much as possible out of them.

8.1.3 Maximising Pumping Times

For economic reasons, it is usually advantageous to design irrigation systems to run for 22-24 hours per day to be able to meet peak demand. This is because peak demand only occurs for one to three months each year, and in the shoulders of the season, the system can be operated for less days per week or less hours per day.

Designing irrigation systems to meet peak demand in a shorter time period means higher flow rates, larger pumps, pipes, higher application rates, and higher capital and operating costs than systems operated over longer time periods.

Over half of the irrigation systems audited were designed to operate (or were operated) over 12-15 hours per day. The two arguments used to support this are the ability to use a greater percentage of night rate electricity and the ability to irrigate when it is less windy. Detailed analysis almost always shows that when all costs (capital and operating) are considered, it is rare to find a system operating on, say, 12 hours per day to be cheaper than on operating on 24 hours per day. Where high pressure systems (such as big guns) are used, wind is an important factor; but regardless of the systems used, they should be designed to operate as efficiently as possible in windy conditions.

8.2 Overall Capacity of Systems

8.2.1 System Capacity

The required system capacities (the amount of water needed to meet the water demand of the crops grown) of the properties audited varied from 0.41 ℓ/s/ha up to 0.67 ℓ/s/ha.

The actual system capacities, based on the number of hours the systems were reportedly operated, ranged from 0.23 ℓ/s/ha up to 0.65 ℓ/s/ha. On six properties, systems had adequate capacity to meet crop water demand. On the others, capacity was limited and, in some cases, seriously limited.

These findings are consistent with findings in other areas of New Zealand, where cropping and mixed cropping systems predominate.

On some of the properties where system capacity was limited, the systems were operated for less than 22 hours per day. By increasing the operating hours per day (e.g. by slowing a travelling irrigator down), capacity could be increased. However, that may not have been recommended because the depths of water applied could exceed soil water deficits.

8.2.2 Consents

Overall, the relationship between the amount of water required to meet crop demand measured, in terms of peak pumping rates and volume of water allocated per week), was extremely variable (see Table 5). In some cases, the amount of water allocated was significantly more than necessary. In other cases, it was much less than necessary.

Actual pumping flow rates pumped were, in all cases, less than or close to consented rates. On five farms, actual pumping rates were 40-50% less than the consented rate.

Where pumping rates or required volumes were less than consented, in general, water supply was limited or a smaller area than originally intended was irrigated, reducing demand.

Because of the discrepancy between required rates, actual rates and consented rates, further work is recommended to make consented rates consistent with required or actual use.

8.3 Matching Systems to Soils

The irrigated soils of Hawke's Bay are extremely variable in depth, water holding capacities, readily available water and infiltration rates. There was some concern before this project started that many of the irrigation systems were designed so that they could not apply water at the depths and rates that the soils could accommodate. This was particularly true for some soils, such as the Takapau soils that had relatively high water holding capacities but did not release that water readily.

It became apparent during the study that farmer knowledge of soils on their properties was also variable. Some had detailed soil survey information while others had very little knowledge of basic soil parameters, such as crop rooting depths, water holding capacities and critical deficits. Whether this variability in soil and crop knowledge is also present amongst irrigation designers is not known. However, given the variable requirements of soils in the district, it is an area that needs closer scrutiny.

8.3.1 Application Depths

The basic requirement with irrigating crops is to have the flexibility to apply varying depths of water according to the stage of crop and the soil type. This flexibility is required to prevent over-watering through all stages of crop development and to prevent stress during times of peak demand. Table 6 presents the range of application depths needed for efficient irrigation and compares those depths with the depths typically applied by the irrigation system.

In all cases, the irrigation systems had the ability to be operated so that the depth of water applied did not exceed the readily available soil moisture. In some cases, the depth of water actually applied would exceed soil water deficits because of the way the system was operated, but that is usually a management, rather than a design issue.

Speeding a travelling irrigator up is an easy way of applying less water. However, this can have serious implications for system capacity. If an irrigator operated at a higher speed is not moved after completing its run, the extra down-time reduces system capacity. This usually means that it is only feasible to reduce application depths and maintain system capacity if the system can be operated on a nominal 12-hour (shifted twice daily) run time.

On the fixed systems (i.e. the fixed centre-pivots and the drip and micro systems), the flexibility exists to apply a wide range of depths to match application to soil moisture deficits.

On the moveable systems (i.e. the guns, travelling booms, K Line, long line, linear moves and towable pivots), the flexibility to apply smaller depths while maintaining system capacity is reduced, if system capacity is to be maintained. Of these systems, the guns are most likely to be applying excess water, according to the information obtained.

8.3.2 Application Rates

Table 7 shows that the application rates of the irrigation systems used in Hawke's Bay vary over a wide range. The systems, such as K Line and long line, have low average and instantaneous application rates. Others, such as guns, have low average application rates but high instantaneous application rates. Pivots have low application rates near their centres but rapidly increasing rates towards the ends. Towable units have higher rates because of the need to apply more water per irrigation. Lateral moves have medium-high application rates. Low pressure fixed booms also have high application rates.

The soil infiltration rates also vary over a wide range. It is known that some soils, such as Turamoe soils, can be difficult to wet up because of a tendency for surface sealing; but once wet, absorb water more easily. Slope and crop cover also has a large influence on the ability of soils to absorb water.

The variation in both irrigation system application rates and soil infiltration rates makes it difficult to make judgements about the effect of system application rate on irrigation efficiency. Although there is anecdotal evidence that using systems with very high application rates results in lower crop yields, it is more difficult to determine the effects of medium or high application rates on crop yields. The research has not been done. Adding complexity to the situation is the fact that systems with high application rates often have higher uniformity, which to some extent counter-balances the negative effect of high application rates. Also, many of those systems with high application rates have the ability to apply small amounts of water at each irrigation.

It could be expected from the data presented in Table 7 that all the systems audited, except K Lines, long laterals, micro and drip systems, would have some problems with surface ponding and redistribution. However, very few users reported problems with surface ponding and surface runoff of water due to high application rates. Where it occurred, the systems were generally managed around it by applying water in small depths, for example.

From the data provided, it is very difficult to draw any conclusions about the effect of high application rates. It seems likely that the design of irrigation systems may cause application rates to exceed infiltration rates, causing some surface ponding and redistribution on occasions; but system operators who recognise this effect attempt to operate their systems in a way that minimises the effect. It is also possible that some system operators do not recognise surface ponding and redistribution as a problem, and therefore have not reported it.

8.3.3 Return Intervals

Irrigation systems should be designed to be able to irrigate frequently enough to prevent crop stress. In most cases, the frequency of irrigation peaks during times of highest evapotranspiration, usually December for cropping and mixed cropping farms and January for pastoral and horticultural farms.

The required design return interval is determined by the magnitude of ET during peak periods and the allowable soil moisture deficit for each crop on each soil type. For this reason, required return intervals vary over farms, particularly where a range of crops is grown. Given the low readily available water holding capacities of some soils, required return intervals could be as low as 4-6 days in peak ET periods.

The actual return interval is determined by the physical ability of the irrigation system to cover the property.

On the fixed systems (i.e. the fixed centre-pivots and the drip and micro systems), the flexibility exists to irrigate as frequently as necessary simply by changing the settings of the system. In all cases, these systems were able to irrigate as least as frequently as that required, although they may have been limited in system capacity.

On the moveable systems (i.e. the guns, travelling booms, K Line, long line, linear moves and towable pivots), the return intervals were usually determined by the number of shifts required to cover the irrigated area, based on one shift per day. In almost all farms using these systems, there would be times when shorter return intervals than those currently used would be recommended for optimum production. The exceptions were the Omme boom, the K Line and the long line systems, although the long lines in reality are probably operated on slightly longer return intervals than those actually reported.

The implication of irrigating at longer return intervals than ideally required is primarily loss of production. Farmers deal with this in two main ways. The first is leaving it to nature and hoping that it rains or ET rates are lower than average. The second is by dropping some crops or paddocks out of the rotation, to shorten up the rotation on the remaining crops. This is the option taken by a number of the audited farms where return intervals were excessive and system capacity was limited.

Irrigating at return intervals greater than ideally required also impacts on irrigation application efficiency. Where this happens, soil moisture deficits are increased, which increases application efficiency and allows for better use of rainfall. This is particularly true where the actual depth of water applied is greater than the required depth (refer to Table 6).

It should be apparent from this discussion that there is a positive correlation between optimal production and application efficiency. Decreasing the return interval and applying less water more often, such as by shifting equipment twice daily, will almost always result in higher overall production and higher water application efficiency.

8.4 Application Efficiency

8.4.1 Estimating Application Efficiency

As stated in Section 2.3.4, application efficiency is determined primarily by application uniformity. It is also determined by application rate and systems with high application uniformity sometimes have high application rates, reducing the overall application efficiency. Uniformity depends on several factors such as the design of the system, soil variations, slope, crop cover and size, rooting depth and wind. Application rate depends on the depth of water applied relative to the wetted footprint and watering time of the system. The more uniformly water is applied at an acceptable rate, the greater the application efficiency.

8.4.2 Efficiency Ranges

In general, the systems with the highest application efficiency are those that can apply small amounts of water frequently, such as medium-length centre-pivots, linear move systems and drip and micro systems. Microjets tend to be less efficient than microsprinklers because of their higher application rates and lower uniformity. Centre-pivots, linear move machines and towable pivots will only achieve these high values of application efficiency if the “little and often” principle is applied.

In the next band of decreasing application efficiency are rotary booms and possibly K Line and long line systems. Currently, data on application efficiencies of K Line and long line systems is limited. These systems are placed in this band on the basis of having low application rates, reasonable return intervals, and lower effect from wind. The performance of both K Lines and long lines are very dependent on how they are moved, and poor operation will reduce efficiency significantly. The K Line system may also be applying excess water on some of the lighter soils, reducing efficiency on those soils. As better information becomes available, estimates of application efficiency may change.

In the lower band of application efficiency are guns and high application rate booms, particularly when they are applying large fixed depths of water over longer return intervals, as most of the audited systems are. Guns are most affected by wind, and booms with high application rates are most susceptible to surface redistribution and runoff. Despite the need to irrigate in windy conditions, some of the guns were operated at higher pressures and wider lane spacing than would normally be recommended.

The reduction of daily operating hours of some of the gun systems is an attempt to irrigate during the least windy parts of the day (i.e. through the night and early morning). This will no doubt increase the efficiency of those that have the capacity to operate this way, and efficiency figures higher than those given in Table 9 may be able to be achieved.

8.4.3 Implications of Low Efficiency

Low application efficiency means that a significant proportion of the applied water is lost and does not contribute to production. Whether this is an issue or not, from the farmer's perspective, depends on his production goals, whether sufficient capacity exists to compensate for losses, and whether other issues such as labour, operation and maintenance compensate for the lower production. Local availability, portability, ease of shifting, and the need to irrigate odd-shaped paddocks no doubt influenced some of the farmers in this project to choose to irrigate with hard hose guns, despite the lower efficiency and loss of production.

If excess water was taken and applied to compensate for lower efficiency, and water was a limited resource in a district, questions could be asked about allocating excess water to inefficient systems. However, based on the relatively limited system capacities of the irrigation systems audited in the project, none of the farms, except perhaps one, fall into this category.

8.5 Hydraulic and Energy Efficiency

8.5.1 Pressure Losses Downstream from Headworks

Pressure losses within the pipe systems varied widely over the audited systems.

About half of the systems had mainline sizes that provided friction loss and velocities in the normal range expected for a well-designed system. The majority of others had losses slightly above what would normally be expected. In two cases, mainline friction losses were much higher than recommended for good practice.

There is always some friction loss in systems but because there are no standards to work to in determining maximum allowable losses, the friction loss allowed depends primarily on the disposition of the designer. Ideally, the selection of pipe sizes should be made on the basis of minimising the total annual costs (annualised capital investment plus annual operating cost), but this is almost never done.

High loss has very little effect on water use and irrigation efficiency provided that correct operating pressures at the outlets are maintained. This can be achieved by ensuring that headworks pressure is high enough to overcome the loss. In this situation, the issue is one of energy efficiency rather than water use efficiency.

Where high losses create problems is where outlet pressures become too low, and the low pressure affects the distribution uniformity of the system, reducing application efficiency.

8.5.2 Headworks Pressures

The difference between the pressure required at the start of the mainline system and the pressure available gives an indication of how well the pump duty matches the required duty. Where available pressure exceeds required pressure, throttling of the pump is required, which results in poor energy efficiency. Where available pressure is less than required pressure, the system will not operate at its design pressure and some loss of efficiency through poorer distribution uniformity would be expected.

As can be seen in Table 12, about half of the systems audited had headworks pressures significantly in excess of that required. In most cases, this was caused by changes in system types from high-pressure guns to systems that operate at lower pressure. To improve energy efficiency, a means of reducing pump pressure, such as fitting a variable frequency drive, trimming pump impellers or replacing the pump, should be implemented.

In general, sufficient pressure was available to operate most systems at the design pressure. In two cases, pressure may have been marginally low, but changes to irrigation management or a small improvement in mainline size would rectify this.

Systems that contain more than one type of irrigation method operating at different pressures usually need to provide enough pressure to operate the irrigator requiring the highest pressure. When this is the case, there is wasted energy as the pressure has to be reduced to the other system types. This was the situation on one of the audited systems, where pressure reduction was necessary. An alternative method of accommodating different operating pressures was used on another system. The main pump was sized to meet the demands of the lower pressure system, and a diesel-driven booster pump was used to boost pressure to the higher pressure system. However, there is considerable inconvenience in having to operate a diesel-driven pump within an irrigation system.

In some systems, improvements to the irrigation system layout or mainline sizes would enable a further reduction in required headworks pressure. A comparison of optimum headworks pressures and actual headworks pressures shows that large differences occurred in the two cases described in Section 8.5.1. Large improvements could be achieved on these systems.

8.5.3 Power Ratings

Power ratings give an indication of overall energy efficiency (pump and motor efficiency for electric systems, and motor and pump and overall energy provided from diesel for diesel-driven systems) and how much energy is required to provide the required duty for the irrigation system. Providing the correct duty (i.e, required headworks pressure is equal to available headworks pressure) does not necessarily mean that a pump is operating at its most efficient point.

Table 13 gives power ratings for the systems as audited, the systems assuming that pump selection was correct and the systems assuming that design changes were made to improve overall hydraulic efficiency.

In the majority of cases, actual power ratings were close to the correct pump power ratings. The greatest differences were caused by pumps providing excess pressure rather than pumps not operating at their maximum efficiency point. In most systems, minor improvements could be achieved by installing a more efficient pump or a pump operating at its maximum efficiency point.

In half of the audited systems, significant reductions in energy use could be achieved by selecting a pump that better matched the required duty or by improving the hydraulics of the system or both.

9 CONCLUSIONS

If the fifteen irrigation systems that were audited in this project are representative of the systems used in the Hawke's Bay district, it must be concluded that the standard of the design is extremely variable. Although some systems are designed well enough to provide the potential to be used efficiently, some are not. Significant improvements in water, labour and energy efficiency could be achieved on these properties.

9.1 System Design and Operation Limitations

One of the most basic irrigation design principles is, wherever possible, to design the farm around the irrigation system. The majority of the irrigation systems audited in this study appear to have been designed around the farm, resulting in systems that are more expensive to install, harder to operate and maintain, more expensive to run, and substandard in performance.

A wide variety of soil properties and crop types are present in the district. A high standard of design is needed to ensure that the system type is matched to crop and soil requirements. Farmer knowledge of crop rooting depth and available water holding capacities of soils was variable. Some had detailed understanding, while others had very little knowledge of basic soil parameters. However, given the variable requirements of soils in the district, it is an area that needs closer scrutiny.

The required system capacities of the properties audited varied from 0.41 ℓ/s/ha up to 0.67 ℓ/s/ha. Actual system capacities ranged from 0.23 ℓ/s/ha up to 0.62 ℓ/s/ha, with only six properties having adequate capacity to meet crop water demand. On the others, capacity was limited and, in some cases, seriously limited. There was potential for increasing system capacity on some systems by increasing the operating hours per day. The amount of water allocated through resource consents was, in some cases, significantly more than necessary. In other cases, it was much less than necessary.

All irrigation systems had the ability to be operated so that the depth of water applied did not exceed the readily available soil moisture. However, applying small depths of water on some systems would reduce overall system capacity.

It is likely that the design of some of the irrigation systems will cause application rates to exceed infiltration rates, thus resulting in some surface ponding and redistribution on occasions.

The flexibility provided by the fixed irrigation systems allowed irrigation to occur as frequently as necessary, provided that they had sufficient system capacity. On most of the moveable systems, there are times when shorter return intervals than those currently used would be recommended for optimum production.

The systems with the highest application efficiency are the medium-length centre-pivots, linear move systems, and drip and micro systems if they are operated to apply small depths of water on a regular basis. Slightly less efficient are rotary booms and possibly K Line and long line systems. The systems with the lowest application efficiency are guns and high application rate booms, particularly when they are applying large fixed depths of water over longer return intervals as many of the audited systems are. It should be noted that several of the audited properties had previously used high-pressure guns and converted to more efficient low pressure systems.

Pressure losses within the pipe systems varied widely, with most close to those expected for a well-designed system. In two cases, mainline friction losses were much higher than recommended for good practice.

About half of the systems had headworks pressures significantly in excess of that required. In most cases, this was caused by changes in system types from high-pressure guns to systems that operate at lower pressure without modifying pump pressure. Sufficient pressure was available to operate most systems at the design pressure. Systems containing more than one type of irrigation method operating at different pressures wasted significant amounts of energy.

In half of the audited systems, significant reductions in energy use could be achieved by selecting a pump that better matched the required duty or by improving the hydraulics of the system.

9.2 Irrigation Performance Indicators

The following performance indicators relating to design factors were used to assess irrigation system efficiency. These indicators were calculated or estimated and compared to the values expected for a well-designed system (see Tables 4 to 13).

$$\text{Application efficiency} = \frac{\text{Water stored in the crop root zone (mm)}}{\text{Total water applied to the soil (mm)}}$$

$$\text{System capacity} = \frac{\text{Irrigation system flow (}\ell\text{/s averaged over 24 hours)}}{\text{Area irrigated (ha)}}$$

$$\text{Return interval} = \text{Number of days between subsequent irrigations}$$

$$\text{Hydraulic efficiency} = \frac{\text{Pressure required at outlets of system (kPa)}}{\text{Pressure supplied at system headworks (kPa)}}$$

$$\text{Energy use efficiency} = \frac{\text{Metered pump power (kW)}}{\text{Pump flow rate (m}^3\text{/h)}}$$

Also recommended, but not calculated due to lack of sufficient data:

$$\text{Water use efficiency} = \frac{\text{Production (kg/ha)}}{\text{Water used (m}^3\text{/ha)}}$$

10 RECOMMENDATIONS FOR IMPROVING EFFICIENCY THROUGH BETTER DESIGN

Although each system audited has specific recommendations for improvements, some fundamental irrigation design limitations have become apparent. The following general recommendations are made to rectify those limitations and to provide guidance for the design of new systems.

1. Understand basic irrigation requirements and soil-plant water needs

Make sure that both farmers and irrigation system designers understand soil water holding capacities, crop root depths, pans, critical deficits, soil infiltration rates, water tables and water usage rates and design irrigation systems to match these parameters. Hawke's Bay soils can be particularly difficult, and understanding soil properties is critical to good design. To ensure this happens will require farmer education and training for irrigation system designers.

2. Design the farm around the irrigation system

Treat irrigation as an integral part of the farm business, not as an insurance policy. Change the farm layout to accommodate the best possible irrigation system design. If necessary, move trees, fences, small waterways, buildings and roads to create an efficient system, both in terms of the operation of the irrigation system and the operation of the property as a whole.

3. Use efficient application systems

Whenever possible, choose a system that has very uniform water application with the lowest practicable application rates. This will ensure that the farmer at least has the potential to make the best use of the available water.

4. Ensure that the system is designed to an acceptable standard

Although there are no formal standards for the design of irrigation systems in New Zealand, information on design is now available – e.g. *The New Zealand Irrigation Manual* (MLG, 2001), *The Irrigation Guide* (FIMG, in press), and *Design Guidelines for Efficient Energy Use* (LE, in preparation).

Have the systems audited by an independent irrigation design expert.

5. Improve energy efficiency

Be aware that if you are throttling your pump at the headworks, you will be wasting energy. A means of reducing pump pressure, such as fitting a variable frequency drive, trimming pump impellers or replacing the pump, should be implemented. In some systems, improvements to the irrigation system layout or mainline sizes would enable a further reduction in required headworks pressure.

6. Keep good records

Make sure that you have detailed plans and specifications of your irrigation systems as they are installed. Without these records, it is difficult to carry out detailed audits or troubleshoot the system if things go wrong.

11 REFERENCES

Borrie, N and McIndoe, I (1998): Financial benefits of making improvements to an irrigation system: A case study. Report No 2780/2, prepared for MAF. Lincoln Environmental, a division of Lincoln Ventures Ltd.

Bright, J; Carran, P; McIndoe, I (1998): Designing effective and efficient irrigation systems. Report No 2788/1, prepared for MAF. Lincoln Environmental, a division of Lincoln Ventures Ltd.

Clemmens, AJ (2000): Measuring and improving irrigation performance at the field level. *Proceedings of the 2000 National Conference and Exhibition, Irrigation Association of Australia.*

FIMG (in press): The irrigation guide – A guide to decision-making when going irrigating. Farmers Irrigation Management Group.

John, PH; Lees, DM; English, GM (1985): Application performance of travelling irrigators. Report No 35. New Zealand Agricultural Engineering Institute, Lincoln University.

LE (in preparation): Design guidelines for efficient energy use. Lincoln Environmental, a division of Lincoln Ventures Ltd.

McIndoe, I and Carran, P (1998): Testing of best management guidelines. Report No 2780/1, prepared for MAF. Lincoln Environmental, a division of Lincoln Ventures Ltd.

MLG (2001): *The New Zealand irrigation manual.* Malvern Landcare Group and Environment Canterbury.

Painter, D and Carran, P (1978): What is irrigation efficiency? *Water and Soil* **14**. National Water & Soil Conservation Organisation and NZ Forest Service.

SANZ (1973): *The design, installation and operation of sprinkler irrigation systems.* Publication 5103:1973. Standards Association of New Zealand.

Solomon, KH (1988): Irrigation systems and water application efficiencies. Center for Irrigation Technology research notes, California State University, Fresno, California.