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Irrigation Efficiency and Water Allocation in the Waihou Catchment

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Study

Irrigation Efficiency and Water Allocation in the Waihou Catchment

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EXECUTIVE SUMMARY

The purpose of this study is to evaluate the efficiency of irrigation water use and allocation in the Waihou catchment. It follows on from similar work for other parts of the Waikato Region. It will further extend the understanding of water use and allocation in the Region and contribute to the development of water management policy and planning.

The surface water resources of the Waihou catchment are close to full allocation. Future demand for surface water will need to be met from improvements in efficiency of current water uses and allocations. Irrigation accounts for 50% of the daily take, and therefore any improvements in on-farm water use and/or allocations will be a major benefit. This is applicable to not only the Waihou catchment, but, also to other catchments where water resources are a constraint to future development.

Irrigation Efficiency

The two key elements of irrigation efficiency are application uniformity and system management. Application uniformity is principally determined by system design: selection of sprinkler type, sprinkler spacing, pipe sizes, operating pressures etc. Management determines how effectively irrigation is scheduled to meet crop water requirements (i.e. timing and application depth). The combination of these two elements determines on-farm irrigation efficiency.

The determination of irrigation efficiency and potential improvements is based on a case study of 10 dairy farms. The evaluation is based on determination of a) system irrigation efficiency (i.e. combination of system performance and management), and b) seasonal irrigation efficiency (i.e. comparison of irrigation demand versus actual water use).

System efficiencies were relatively high, with all systems greater than 70%. However, in some cases high efficiencies were the result of constraints on system capacity (i.e. systems were under-designed for the irrigated area, rather than high application uniformity). Long-laterals, the most prevalent system type, were in the 70-85% efficiency range. Efficiencies for K Lines and gun irrigators were higher than expected (more than 75%), but this is largely due to system constraints rather than high uniformity.

Seasonal irrigation efficiencies were reasonably consistent with the system efficiencies. However, the analysis was limited by the accuracy and completeness of water use records.

Potential improvements to system performance relate to better system design, such as: mainline pressure regulation for systems with elevation extremes, upgrading of mainline design (for systems with high pressure losses), variable speed control of pumps on multiple gun systems and systematic irrigation scheduling.

The results indicate that current systems and management are relatively efficient, and that improvements in application uniformity and management will principally improve on-farm water use efficiency (i.e. grow more grass, rather than release an under-utilised resource for reallocation).

Water Use Efficiency
The average annual response to irrigation is approximately 4,000 kg DM/ha or the equivalent of 14 kg DM per millimetre of irrigation.

Based on current payout levels ($4.20/kg MS), the marginal benefit of irrigation is $300 to $400 per hectare dependent on irrigation system type (the variation in benefit relates to difference in system uniformity and costs). The analysis shows that irrigation is a relatively low cost way of producing dry matter, with a unit cost of 12 to 14 cents per kg DM, compared to 15 to 20 cents for silage and concentrates.

The study findings show that irrigation is a cost effective and profitable way of producing grass for dairy farms over a range of payout levels. Where there is ready access to water resources it serves to both increase and reliably maintain farm production. The implication is that there is likely to be continued development of irrigation in the Waihou and other areas of the Waikato. This development will bring benefits to individual farmers, local communities and the Region as a whole, in terms of production, investment, income and employment. But, it will depend on the availability of water resources to reliably meet irrigation demand.

Allocation Efficiency and Options
The evaluation of current irrigation allocations from surface water indicated that at best, during drought years, allocation efficiency is 50% and in an average year less than 30%. The current process is constrained by a) take rates higher than the nominal daily rate (i.e. take rates based on 12-hour irrigation) and b) lower water demand on the margins of the irrigation season (November-December and March-April). Improvements in allocation processes to address these constraints could provide water for the irrigation of a further 1,100 hectares (an increase of 70% over the current area) with a cumulative increase in returns of $400,000 per year and land values of $7 million.

The options for improving allocation efficiency are:

a) Takes at a rate higher than the 24-hour rate (or a nominal irrigation day, i.e. 20 hours) and above a minimum threshold (e.g. 5 ℓ/s) conditional on the following:
    - Specification of take period per day (i.e. hh:mm to hh:mm);
    - Electronic logging of takes to ensure compliance with take period and daily volume.

b) Specification of irrigation season as November to April, to establish the limits of the period within which the take days are allocated (retain the current take days, 90-120 days). The benefit being that the period of irrigation demand can be determined for evaluation of cumulative effects.

c) Establishment of stepped irrigation demand for the season margins (i.e. November-December and March-April), with cumulative daily allocation per month based on a percentage of peak demand (approximately 60% of maximum daily allocation). This would enable the allocation of complementary seasonal demand within the irrigation season margins such as for frost protection.

d) Establish a secondary class of take consents (B share), for either under-utilized allocations (for example seasonal irrigation takes) and/or allocations above current water availability criteria. The secondary take would be restricted at a higher flow threshold than current allocations (i.e. % above Q_5), and therefore be less reliable.

1 INTRODUCTION

This study forms part of an ongoing commitment by Environment Waikato to the development of water resource planning and management. It follows on from previous work determining irrigation requirements and efficiency in other areas. The findings of this study will contribute to a better understanding of water use and allocation issues to assist in the refinement of management processes and procedures.

The overall purpose is to evaluate the efficiency of irrigation water use and allocation in the Waihou catchment. There are a number of issues related to the reliability of water resources, particularly surface water availability to meet increasing demand. The study investigated issues related to the efficiency of irrigation water use and allocation, and proposes options for alternative allocation procedures.

1.1 Previous Work

As mentioned above, this study is part of an on-going commitment to develop water management in Waikato Region. There have been a number of other relevant studies in the Region. These include:

- Cropwater requirements for irrigation in the Waikato Region – The study by Landcare determined irrigation requirements for a range of locations, soils and crops (Landcare, 1997). The study findings form the basis for irrigation allocations and efficient irrigation use as defined in the Regional Plan (Plan Table 3.4). The listed soils include Netherton that occurs on the lower Hauraki Plain (including the lower Waihou), for which annual (mean annual) and daily requirements for pasture are 466 mm and 45 m^3/ha/d, respectively.
- Investigation of efficiency of water allocation and use – The study investigated the irrigation efficiency of a case study of market gardens in the Pukekohe area and assessed water allocation efficiency more generally in the Region (LE, 2002). The analysis of allocation efficiency included a sample of dairy farms on the Hauraki Plain. It indicated in some cases that allocable resources were being under-utilised due to system and management constraints.
- Investigating dairy farm irrigation efficiency in the Reporoa Basin – The study completed in June 2002 investigated irrigation and water use efficiency on dairy farms in the Reporoa Basin of South Waikato. The results show that irrigation is a key component of farm productivity and that while irrigation efficiency was high, application uniformity was a constraint to system productivity. In the Reporoa area, water use efficiency for dairy farms is typically in the order of 12 kilograms of dry matter per millimetre of irrigation (kg DM/mm), with marginal benefit of about $350/ha/y.
- Study of the Hauraki water scheme – In 2002, Tonkin and Taylor investigated issues related to the impact of water turbidity on the scheme performance. It found that high turbidity levels occurred when low flows coincided with king tides, which reduced system water treatment

performance and therefore supply. This information was instrumental in defining current restrictions on upstream takes.

- Water management study – A study is currently being completed to identify options for development of water management in the Waikato Region. While the study outcomes are regional, the Waihou catchment forms the case example for the study to demonstrate specific allocation and management issues and options (ARL, 2004).

1.2 Study Description

The principal objective of the study is the determination of the efficiency of irrigation and water allocation in the Waihou catchment. This will be determined through the evaluation of four principal elements. These are:

- Irrigation efficiency – Determination of system and seasonal efficiency for case samples of pastoral irrigation systems.
- Water use efficiency – Determination of water use efficiency for pastoral irrigation.
- Water allocation efficiency – Determination of current water allocation efficiency within the catchment.
- Allocation scenarios – Identification of alternative water allocation options.

Appendix A lists the study objectives, methods and outputs as presented in the proposal for services.

1.3 Waihou Catchment

As the project title indicates, the project is focused on water use in the Waihou catchment. The key features of the catchment relevant to this study are summarised below.

Physiographic and Land Use Features
The Waihou catchment is approximately 2,000 km^2 in area, being 120 kilometres in length and 20 kilometres at the widest point. The south and west of the catchment is dominated by the Mamaku Plateau and Kaimai Ranges respectively, with extensive exotic and native forests (Figure 1). The east and north form part of the Hauraki flood plain on which livestock farming, particularly dairying, is the main land use. Approximately 60% of the total area is currently in land uses associated with livestock farming.

Water Resources
The Waihou River and tributary rivers (Ohinemuri and Hikutaia) and streams are the principal water resource for consumptive use. Based on current allocation criteria the allocable surface water resources are in the order of 2.4 m^3/s or the equivalent of more than 75 million cubic metres per year (Mm^3/y).

There are also extensive groundwater resources, some of which are thermal in nature. Shallow groundwater has been developed in middle and upper catchment areas for domestic and livestock supply. Water quality in the lower catchment is poor with high iron content, and is generally unsuitable for consumptive uses. Thermal groundwater has been developed at Okauia and Te Poi for recreational use.

Water Use

Consumptive water use is associated with domestic requirements for the towns of Matamata, Paeroa, Waihi, Putaruru and Tirau (as well as a number of smaller communities), irrigation, industry and livestock requirements. In addition to community supply networks there are a number of rural water supply schemes (Hauraki Plains, Ohinemuri, Puriri and Hikutaia) in the lower catchment. Irrigation accounts for approximately 50% of the current allocated take rate and 40% of annual water usage. Domestic and rural water supplies account for 30% and 40% of take rate and annual usage respectively (ARL, 2004).

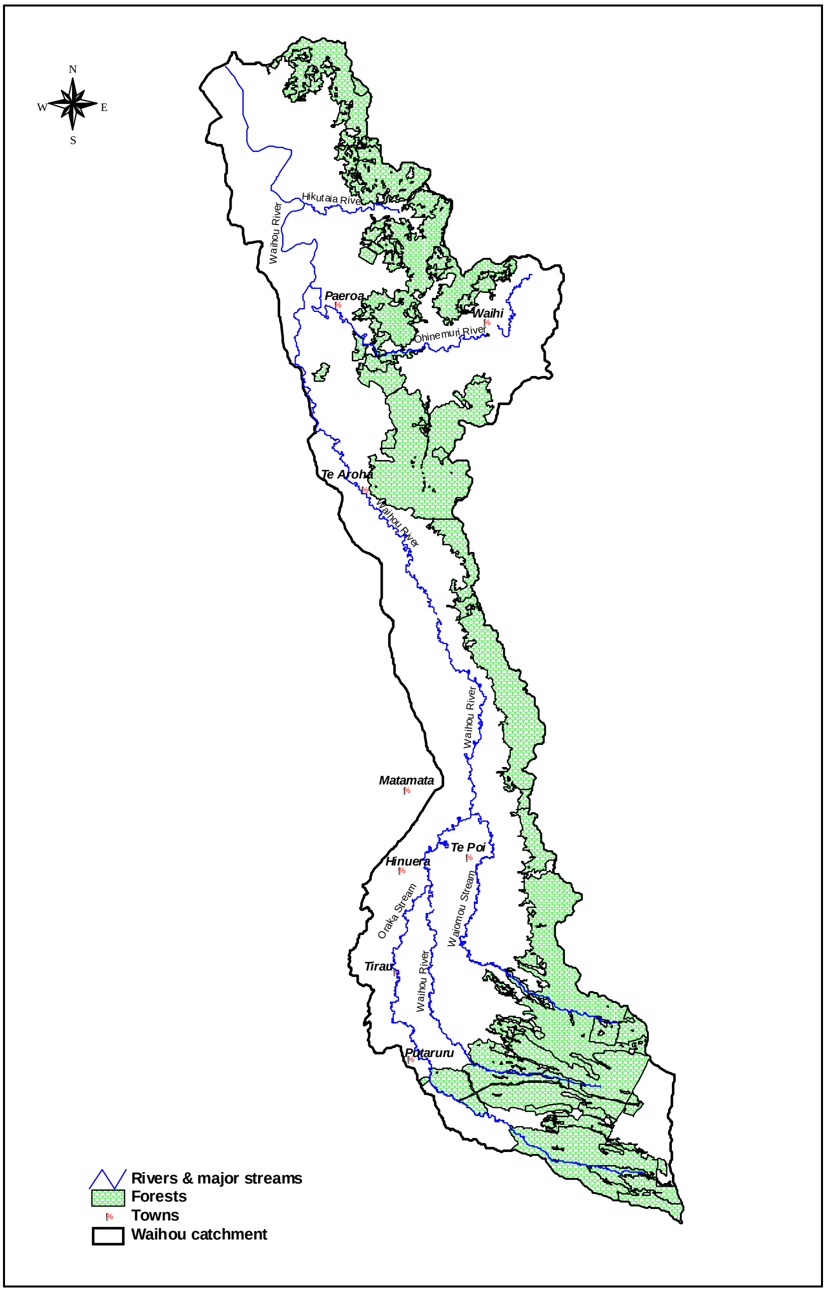

Figure 1: Study area and main features

Water Management Issues

The key water management issues in the Waihou catchment are:

- Increasing demand for water for irrigation, domestic and industrial use. There has been an expansion of irrigation in the past 10 years, mainly for irrigation of pasture on dairy farms (as in other parts of the Region and other Regions). Some supply networks are also experiencing increased demand, for both domestic and industry needs. This raises concerns over the impact on resource sustainability and management processes to ensure efficiency of water use.
- Water take restrictions: the flow requirements (at high tide) for the Hauraki Plains Scheme intake at Kerepehi places take limitations on upstream takes during periods of low flow.

1.4 Information and Data Sources

This study draws on information and data from the following sources:

- Environment Waikato – catchment maps, flow records, consent records.
- NIWA – climate data for irrigation demand modelling.
- Field survey of irrigated farms (10) for the provision of system type and irrigation management information.

2 IRRIGATION EFFICIENCY

As indicated above, irrigation water use accounts for approximately half of consented takes. It is therefore a key component of overall resource use within the Waihou catchment, particularly as most of this water comes from surface water sources.

The purpose of this section is therefore to assess issues related to the efficiency of irrigation water use. This is determined at the farm level with an evaluation of system efficiencies and the response to water in terms of farm productivity and returns.

Most of the current irrigation takes are for irrigation systems on dairy farms, therefore this evaluation is based on these systems and farm responses. Dairy farming is the agricultural sub-sector in which there has been the greatest increase in irrigation in recent years, due in part to good returns and an industry trend towards intensification of production. As recently reported by Fonterra, this trend is predicted to continue at least in the medium term. Hence there is likely to be further expansion of pastoral irrigation in the Waihou and more generally within the Waikato Region. Further understanding of the factors and issues related to pastoral irrigation and the role of irrigation in dairy farming will help refine current water allocation processes and procedures.

2.1 Irrigation Efficiency

There are numerous definitions of irrigation efficiency, the applicability of which are generally related to factors of system scale and time frame. Two definitions are adopted in this study. These are:

- System irrigation efficiency. This is defined as the efficiency of the irrigation system over an irrigation cycle. It is determined from two elements, system uniformity and system management.
- Seasonal irrigation efficiency. The efficiency of irrigation over a number of cycles, ranging from a month to a season, determined as the ratio of irrigation requirement to recorded water use.

As outlined in Section 1.1, the allocation of takes for irrigation in the Waikato is based on the work by Landcare on irrigation requirements (Landcare, 1997). The requirements included an assumed system uniformity of application, commonly defined as the coefficient of uniformity (CU). The value adopted in the above study was a CU of 70% which is regarded as a typical and achievable level of uniformity for sprinkler and spray irrigation systems under field conditions. The equivalent application efficiency for a system with an application depth (irrigation depth) equivalent to crop water requirements will be in the order of 80 to 85%.

While the above approach is generally a practical and reasonable approach for allocating water for irrigation, there is little information on actual system performance. This is due in part to the difficulty and cost of directly measuring system performance. The purpose of this section is therefore, within the reasonable limits (time and information), to review the likely performance of irrigation systems used for pasture irrigation in the Waihou catchment.

2.2 Case Study Farms

The approach in this study is to evaluate efficiency levels for a sample of ten irrigation systems on ten farms. These systems were selected from a shortlist of 17 systems with reasonably complete information on system type, irrigated area and water use records.

The method for determination of farm and seasonal irrigation efficiencies is summarised as:

- Field survey of selected farms (10) to collate information on system design and operation. The surveys were conducted during Mar-May 2004, which entailed farm visits, farmer interview and system inspection.
- Determination of farm irrigation efficiency based on:
  - System design analysis for determination of application uniformity
  - Mainline hydraulic analysis to determine system pressure variations
  - Calculation of system uniformity and application uniformity from elements of application uniformity, application rates and system operation.

- Soil moisture modelling of daily time series to determine irrigation requirements (also used as the basis for the analysis of pasture production response in Section 3).
- Determination of seasonal irrigation efficiency based on comparison of modelled irrigation demand and actual water use (Section 2.4).

The ten sample farms are summarised as:

- Total farm area of 1,460 hectares
- Total milking cows of approximately 4,850
- Total milk solids production of more than 1.5 million kilogram of milk solid for the 2003-04 season
- Combined maximum daily take of 41,270 cubic metres per day, with all takes from surface water sources
- Irrigated area of approximately 1,330 ha
- System types included:
  - Long-lateral (6)
  - K Lines (2)
  - Centre-pivot (2)
  - Travelling gun irrigators (2)

On one farm the system was a combination of types (i.e. centre-pivot (2) and long-lateral).

Appendix B lists a summary of the case farm details.

2.3 System Irrigation Efficiency

The determination of system irrigation efficiency is based on a combination of system performance and management. The former element is determined from an assessment of application efficiency, taking into consideration sprinkler type and spacing and the impact of pressure variations within the system on uniformity. Appendix C lists details of the approach and methods adopted for the determination of system irrigation efficiency.

2.3.1 Results

Table 1 presents the results of the analysis of efficiency for systems on the case farms, as System IE (%). It also lists the system uniformity and management elements to assist with the explanation of system irrigation efficiencies below. Key points regarding the results are:

- Long-laterals – System efficiencies are within the range of 70-85% which largely reflects that the systems are generally well designed. However, there are considerable elevation differences on some farms, with resultant low pressure areas which reduce uniformity and overall efficiency.
- K Lines – Have slightly lower uniformity than the long-laterals, due to relatively wide sprinkler spacing (and lower discharge sprinklers). The

exceptionally high efficiency value for Farm 10, is a function of an inadequate system capacity (about half what is actually required) and excessive pressure loss within the system (due to small mainline pipe diameters).

- Guns – Uniformity is lower than for other systems, but with a relatively good efficiency level for the guns on Farm 1. The high efficiency level on Farm 4 is due to inadequate system capacity to meet peak irrigation demand.
- Centre-pivots – The uniformity value is based on design values (due to the time and resource constraints for direct measurement). However, this appears to be a reasonable approach, which is vindicated by the seasonal irrigation efficiency values in Section 2.4.

Table 1: System irrigation efficiency

Farm No	System	System CU	Management IE %	System IE %
1	Gun	69	90	75
2	Long-lateral	78	82	71
3	Long-lateral	86	91	84
4	Gun	69	119	104
5	Long-lateral	78	101	90
6	Long-lateral	86	91	84
6	Pivot	87	91	85
7	Long-lateral	64	91	73
8	Long-lateral	74	91	78
9	K Line	77	91	79
10	K Line	64	248	230

2.3.2 Improving Efficiency

The above efficiencies indicate that the systems appear in general to be designed to achieve satisfactory levels of efficiency. The approach to designing irrigation systems for dairy farms is to create systems that are relatively simple and robust. The systems usually do not have any form of pressure regulation, and are designed to operate as a single unit. While the approach is a practical one, there are invariably compromises to achieve this simplicity, particularly on large-scale systems.

Below are a series of comments from the analysis and field observation on sources of inefficiency and potential improvements. These are:

- Long-laterals; the biggest constraint on the system performance was due to elevation variations within farm, which created areas of low and high pressure. These variations are overcome to some extent by sprinkler nozzle size selection, but not entirely. The problem could be overcome with use of pressure regulation on mainline or branch mains, but is possibly too costly for the perceived performance benefits. However, as indicated in the Reporoa irrigation study, improvements in application uniformity (through better pressure regulation) produce significant and profitable increases in returns (LE, 2003). Another issue is operator skill in moving sprinklers to achieve good overlap between events and high uniformity.

- High mainline losses; on one system (K Line) there were excessive mainline pressure losses due to poor design (selection of small pipe diameters), resulting in a reduction in application uniformity. The system could be improved with replacement of mainline sections, and/or installation of a ring-main.
- High operating pressure; on one system operating two guns, high headworks pressures occurred due to run location combinations or when a single gun was operating. While the installation of a pressure regulating valve had partially resolved the problem, a better and more economic solution is the installation of a variable speed drive for the pump motor. The drive would ensure the correct operating pressure downstream of the headworks and reduce motor power consumption.
- Efficiency on season margins; the analysis is based on peak irrigation demand. What is not able to be assessed is the likely efficiency level during periods of lower demand, such as early or late in the irrigation season, or during intermittent operation. This will depend to some extent on operator skill in interpreting irrigation requirements. At the moment in the Waihou, this is largely an individual operator decision.

2.4 Seasonal Irrigation Efficiency

The determination of seasonal irrigation efficiency is based on a comparison between irrigation demand and actual water use. As outlined in Appendix D, irrigation demand is determined by modelling of daily soil moisture levels over the period of water use records. Actual water use is determined from water use records provided by Environment Waikato for the case farms. The approach is a global farm approach, which is dependent on the accuracy of records and a number of assumptions and parameters. While there are a number of constraints in the overall approach, it is nevertheless a useful indicator of longer term (longer than individual irrigation cycle) efficiency levels. It is useful in highlighting broader issues regarding the use and operation and management of irrigation on dairy farms.

2.4.1 Results and Issues

An initial evaluation of entire season efficiency yielded exceptionally high efficiency values (multiples of 100%); however, this was due to incomplete water use records. An evaluation of efficiency based on period of water use records gives more reasonable values for some farms.

Table 2 shows a summary of seasonal application efficiencies based on part-season records. It shows highly variable results between farms and seasons. While the results are dependent on somewhat incomplete water use records, they nevertheless indicate a number of interesting points, including the following:

- Efficiency levels of greater than 100% indicate either incomplete water use records and/or under-irrigation. The latter may be particularly relevant to travelling gun irrigator systems, due to the labour requirements and limitation of shifting large gun systems. It may also be due in part to the fact that gun systems are often regarded as supplementary systems, intended to meet less than full irrigation requirements.
- Results for the long-lateral systems appear to be more consistent with expected values, largely within the range of 55 to 80% and reasonably consistent with the system irrigation efficiency levels above.
- The single season result for the centre-pivot/long-lateral system at 83% is at the level anticipated for pivots; this is very similar to the calculated value above.
- The K Line efficiency levels for the 2002-03 season both exceed 100%. On Farm 10 the explanation is that the system is grossly under-irrigating due to the limitations of the current take rates, at about 50% of actual requirements.

Table 2: Summary of seasonal irrigation efficiency levels

Farm No	System	Irrigation season			
		1999-00	2000-01	2001-02	2002-03
1	Gun		107		151
2	Long-lateral	52	82	49	59
3	Long-lateral	78			
4	Gun		205	74	318
5	Long-lateral				132
6	Pivot/long-lateral			83	
7	Long-lateral		55	81	58
8	Long-lateral				
9	K Line				156
10	K Line				178

Overall the system and seasonal irrigation efficiency levels appear to be reasonably consistent. With the exceptions of very high values due to system capacity limitation, efficiency levels appear to be close to or within the range assumed for resource allocation. The results do not indicate that the system or seasonal efficiency is abnormally low for the case farms.

Appendix E lists the results for the determination of seasonal irrigation efficiencies.

3 WATER USE EFFICIENCY

Previous studies of agricultural irrigation in the Waikato indicate irrigation makes a major contribution to dairy farm production. A study of farms in the Reporoa area found that irrigation was an integral part of strategies to improve and maintain farm productivity (LE, 2003). It increased the reliability of grass production and therefore reduced the risks and uncertainties associated with summer droughts.

The purpose of this section of the study is to determine the current levels of water use efficiency for dairy farming in the Waihou catchment. A better understanding of the productive and financial benefits and returns to irrigation will provide resource planners and managers with greater knowledge of the issues facing farmers regarding the role and benefits of irrigation.

This evaluation is based on the following elements:

- Determination of irrigation demand
- Determination of pasture response to irrigation
- Determination of the cost and benefit of irrigation for dairy farms.

Appendices F and G presents a summary of the methods and assumptions adopted for the determination of the above elements.

3.1 Irrigation Demand

Figure 2 shows seasonal irrigation (Nov-Apr) demand for the period 1992-03. Average demand is approximately 300 mm/season but during prolonged droughts may exceed 380 mm/season. For the purposes of system design, the upper 95 percentile of demand is approximately 370 mm/season, or the equivalent allocation of 3,700 cubic metres per hectare (m^3/ha).

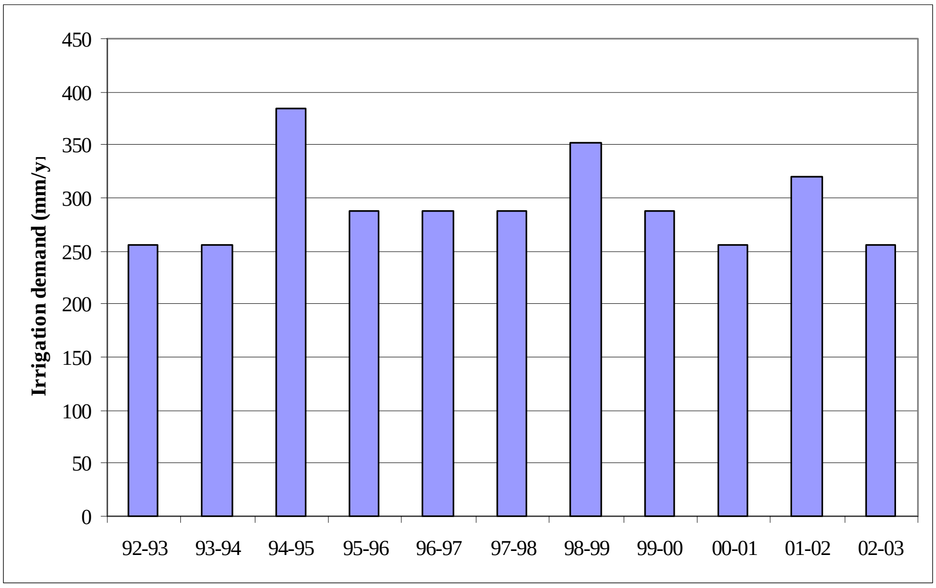

Figure 2: Seasonal irrigation demand (mm/y) (pasture)

3.2 Pasture Response

The determination of pasture response to irrigation is based on the yield relationship to moisture stress during the irrigation season (Nov-Apr). For well irrigated pasture, annual production is estimated to be approximately 17,000 kg DM/ha/y of which about 70% is produced during the November to April period.

Table 3 presents a summary of the modelled pasture response to irrigation for the seasons during the period 1991-2003. It shows the increase in production due to irrigation ranged from 2,300 kg DM/ha in the 00-01 season to more than 6,500 kg DM/ha in 94-95. Over the modelled period, the average increase is just over 4,000 kg DM/ha. The average production increase per unit irrigation depth was 14 kg DM/mm, which is a similar response to irrigation in Reporoa (LE, 2003). The pasture yield response forms the basis for the cost benefit analysis in the next section.

Table 3: Pasture response to irrigation

Season	Response (kg DM/ha)	Irrigation (mm)	Unit response (kg DM/mm)
91-92	3,988	256	16
92-93	3,843	256	15
93-94	3,106	384	8
94-95	6,519	288	23
95-96	3,519	288	12
96-97	3,718	288	13
97-98	4,393	352	12
98-99	4,979	288	17
99-00	4,111	256	16
00-01	2,315	320	7
01-02	4,937	256	19
02-03	2,883	220	13
Average	4,026	288	14

3.3 Cost Benefits Analysis

A useful starting point in determining the benefits of irrigation is a comparison between the stocking rates and production between the study farms and average values for Hauraki District (Hauraki) (LIC, 2003). Table 4 shows a comparison between the two, indicating higher stocking rates and higher per cow and per hectare milk solid production. The evaluation of the benefits of irrigation is based on the difference between those reported for the study farms and the district average. Appendix B lists a summary of stocking rates and milk solids production for the study farms.

Table 4: Comparison of study farms and district dairy values

SR and production	Study farms	District average
Cows per ha	3.6[1]	2.62
Milk solid per cow	1,192	777
Milk solid per ha	328	295

The determination of the cost and benefits of irrigation is based on the following parameters and assumptions:

- An average non-irrigated pasture production of 12,000 kg DM/ha/y.
- An average increase in pasture production of 4,000 kg DM/ha/y.
- The increase in pasture production contributes to an increase in stocking rate (0.5 cows per ha), increased per cow production (30 kg MS/cow), and reduction in imported winter feed requirements.
- Payout rate of $4.20 per kg milk solids, close to current season rate of $4.23.

The benefits of irrigation for four systems (long-lateral, K Lines, centre-pivot and travelling gun irrigators) are summarised in Table 5. The key points to note are:

- Marginal benefit of irrigation ranges from $290 to $380 per hectare, dependent on system type.
- Returns to water (based on irrigation costs (capital and operating) are about 10 cents per cubic metre. These returns are based on system uniformity and application efficiencies typical of the study farms.
- The cost of producing dry matter by irrigation is 12-14 cents per kg DM. This is less than importing supplementary feed alternatives such as concentrates and silage, which is in the order of 15-20 cents per kg DM.

Table 5: Irrigation benefits for irrigation systems

	Irrigation system			
Description	**K Lines**	**Long-lateral**	**Centre-pivot**	**Gun**
Marginal benefits ($/ha)	291	338	380	363
Net returns to water ($/m^3)	0.10	0.11	0.13	0.12
Cost $/kg DM	0.14	0.13	0.12	0.12

The above analysis is inclusive of labour costs, which if discounted (they may be required for alternative activities, i.e. feeding out in summer-autumn), marginal returns and returns to water are higher.

[1] The study farm average is influenced by a very high stocking rate on Farm 6 (5.5 cows/ha). With the exclusion of this farm the average for the remaining nine farms is 3.2 cows per ha, still more than 0.5 cows per ha higher than the district average. These values have been adopted for the water use efficiency analysis.

While the above benefits and returns are based on a payout rate of $4.20/kg MS, the payout rate can vary significantly between seasons. Table 6 shows the sensitivity of marginal benefits and returns to water for payouts between $3.20 and 4.40 /kg MS. The benefits remain positive above $3.90/kg MS, and possibly below this level if labour costs are discounted. This indicates that irrigation is likely to remain an attractive option for dairy farming within the foreseeable future, and therefore demand for water takes is likely to continue to increase.

Table 6: Sensitivity of irrigation benefits to payout

Payout ($/kg MS)	Marginal benefits ($/ha)	Water returns ($/m^3)
3.2	-718	-0.24
3.4	-507	-0.17
3.6	-296	-0.10
3.8	-84	-0.03
4.0	127	0.04
4.2	338	0.11
4.4	549	0.18

4 ALLOCATION EFFICIENCY AND OPTIONS

The purpose of this section is to determine current efficiency of irrigation allocations within the catchment and to identify options and benefits for an alternative allocation approach. Currently, allocations for irrigation and other water takes are based on criteria of maximum daily take and for surface water instantaneous take rate. The rationale for the approach is based on effects on the water source and, in the case of groundwater, on adjacent wells. The allocations may be on a continuous basis (24 hours per day) or a specified daily period (typically 8 or 12 hours) where requested by the applicant and when there are sufficient allocable resources. While the take volume and rate are specified (as well as number of take days for irrigation takes[2]), the consent does not generally specify seasonal period[3] or seasonal variations in take rates.

There are currently 30 consented takes and one consent application for irrigation from surface water in the Waihou catchment, with a combined maximum daily volume of just over 75,000 m^3/d and cumulative take rate of 1,471 ℓ/s. Apart from four takes for golf courses, the balance is for irrigation of pasture (20) and vegetable and fruit crops (7). A summary of number of takes, rates and volumes from surface water is presented in Appendix H.

[2] The duration of irrigation takes is generally 120 days per year, though in some cases may be less (i.e. 90 days).

[3] The period of seasonal takes is generally not specified in consent conditions, though may be listed on the consent application.

The groundwater takes and proposed takes for irrigation total 11, with a combined take rate of less than 4,000 m^3/d. Hence to date, groundwater is a relatively minor contributor to overall irrigation demand at about 5%. The discussion and results below are therefore focused on surface water as this is the resource currently under greatest demand for irrigation and other uses.

The total irrigated area of the above surface water takes, based on known irrigated areas (for case study farms) and from consent records, is approximately 1,500 hectares. Pasture makes up more than 90% of the total irrigated area.

The following subsections present an evaluation of allocation efficiency of water resources for irrigation, and options and alternatives for improvements.

4.1 Peak and Seasonal Irrigation Demand

Figure 3 shows the cumulative daily irrigation demand (m^3/d) per month for takes (current and proposed) within the Waihou catchment. It is calculated from modelled irrigation demand values in Section 2, and presents values for three ranges: mean, maximum (peak), and 95% percentile level. The peak monthly value (75,000 m^3/d) occurs in January and is the same as the cumulative take volume above. The plot shows the distinct seasonal trend, with an increase in demand in late spring, summer peak, decline in April-May and zero winter demand.

Based on maximum monthly demand values, the total annual irrigation requirement is approximately 8.5 Mm^3, while in an average year it is less than 5 Mm^3.

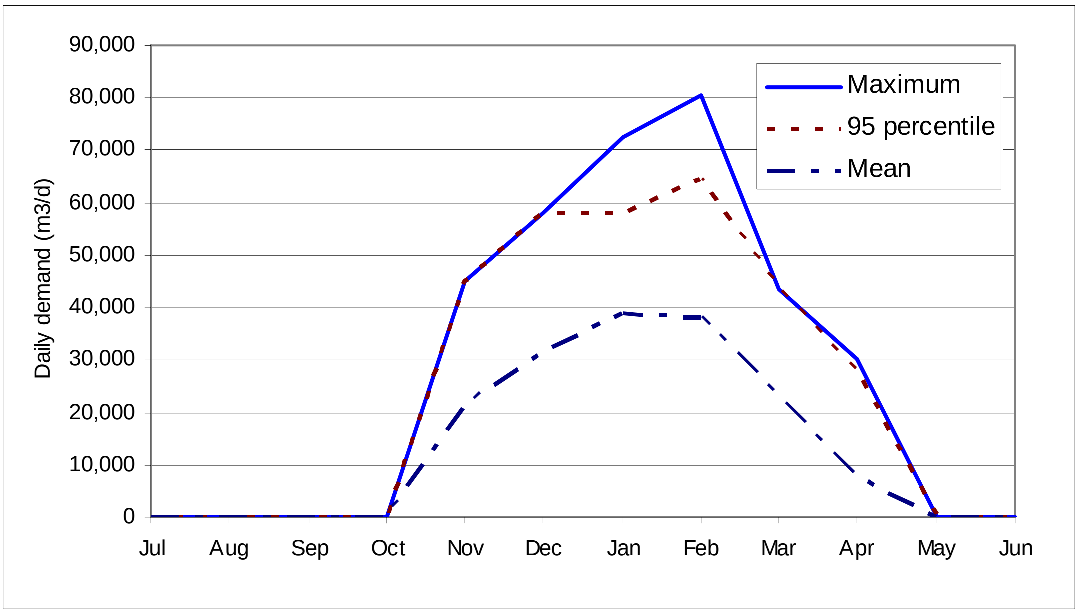

Figure 3: Peak and seasonal irrigation demand

4.2 Allocation Efficiency

The allocable rate and volume of surface water in Waihou catchment is defined by the allocation and catchment in the Proposed Regional Plan. The allocable resources are defined as 10% of the 1-in-5-year low flow value (Q_5) value. The cumulative allocable rate and volume for the catchment as a whole is approximately 2,480 ℓ/s and 214,000 m^3/d respectively. The cumulative take rate of current and proposed consents is close to the allocable limit, indicating that surface water is fully allocated, and that future demand will need to be met from groundwater and alternative surface water options (dams, harvesting of winter flows etc.).

In determining the current efficiency of allocations to irrigation, there are two key issues to consider:

a) A high proportion of takes are based on takes for only a proportion of the day, for example a take of 80 ℓ/s with a daily maximum of 3,500 m^3/d, which is essentially a take of 80 ℓ/s for 12 hours. The higher take rates (than 24-hour based rates) is largely due to irrigation system design and operation requirements, such as 12 hour irrigation cycle to use night rate electricity.

   The cumulative take rate for irrigation is currently 1,470 ℓ/s with maximum daily volume of 75,000 m^3/d. However, if takes are based on a 24-hour take duration, the equivalent cumulative take rate would be 870 ℓ/s for the same cumulative volume. Therefore, the current allocation based on shorter take periods essentially lock-up 600 ℓ/s of allocation or the equivalent of 52,000 m^3/d. This effectively limits allocation efficiency based on daily water use to a maximum of 59%.

   Based on a peak system capacity of 0.55 ℓ/s/ha, 600 ℓ/s is an equivalent irrigated area of 1,100 ha. The direct financial benefit of the use of this resource for irrigation on dairy farms is approximately $400,000/y. There is also additional benefit in increased capital value of land deemed to have access to irrigation, which is in the order of $7 million (based on an increase of $23 per kilogram increase in milk solids production per hectare (289 kg MS/ha).

b) Variations in water demand between and within irrigation seasons. The cumulative annual allocation of surface water for irrigation is approximately 9 Mm^3/y (based on 75,000 m^3/d for 120 take days per season). However, irrigation demand varies between seasons. Table 7 presents a summary of annual irrigation demand for a 22-year period (1980-03), and the range of allocation efficiency levels. It shows that on average, seasonal demand is 4.9 Mm^3, but, can range from 7.9 down to 3.6 Mm^3. The table shows that allocation efficiency on a seasonal basis at best is 85%, but, on average is 54% and in wet years is 40%.

Table 7: Irrigation demand and allocation efficiency

Irrigation demand	Annual demand (Mm^3/y)	Allocation efficiency (%)
Peak	7.6	85
95 percentile	5.8	65
Mean	4.9	54
Minimum	3.6	40

As shown in Figure 3, monthly demand peaks in Jan-Feb, and is lower on the shoulder of the irrigation season, due to lower evapotranspiration. In principle this water is being under-utilized, and could be reallocated to an alternative use during these periods (i.e. frost protection).

The analysis shows that while allocations are designed to meet the peak demand requirement (and therefore ensure supply reliability), for most seasons a considerable proportion of the allocable resource is not utilized on the margins of the season and in some years throughout the season. This represents an allocable resource, with a lower level of supply reliability than current allocations. In catchments at or approaching full allocation, this resource could be utilised to meet at least some of the additional demand.

Figure 4 shows a plot of monthly water allocations and demand (expressed in m^3/d) for the irrigation season taking into consideration the above two points. Points to note are:

- Allocated resource is the volume of water allocated to irrigation, which is 127,000 m^3/d (the daily volume for the allocated take rate above, i.e. 1,470 ℓ/s).
- Take rate is the equivalent daily volume of irrigation (i.e. 75,000 m^3/d).
- Peak irrigation is the maximum irrigation demand from model predictions.
- Under-utilised resource is the combination of water allocated to irrigation use, but not used due to constraints on take rates (point a) and variations in seasonal demand (point b). It represents the resource that is available during a peak demand season. The monthly rate varies from 50,000 to 100,000 m^3/d.

Based on 120 take days per season (generally the specification for irrigation takes), the cumulative effects of take rate (point a) and seasonal variability of demand (point b), there is under-utilization of approximately 7.8 Mm^3 of water in a peak year and 11.3 Mm^3 in an average year. The overall allocation efficiency (based on 127,000 m^3/d) is close to 50% and 26% for peak and average demand years respectively. This indicates that there is potentially a large surface water resource that could be freed up with the adoption of alternative water allocation options as discussed below.

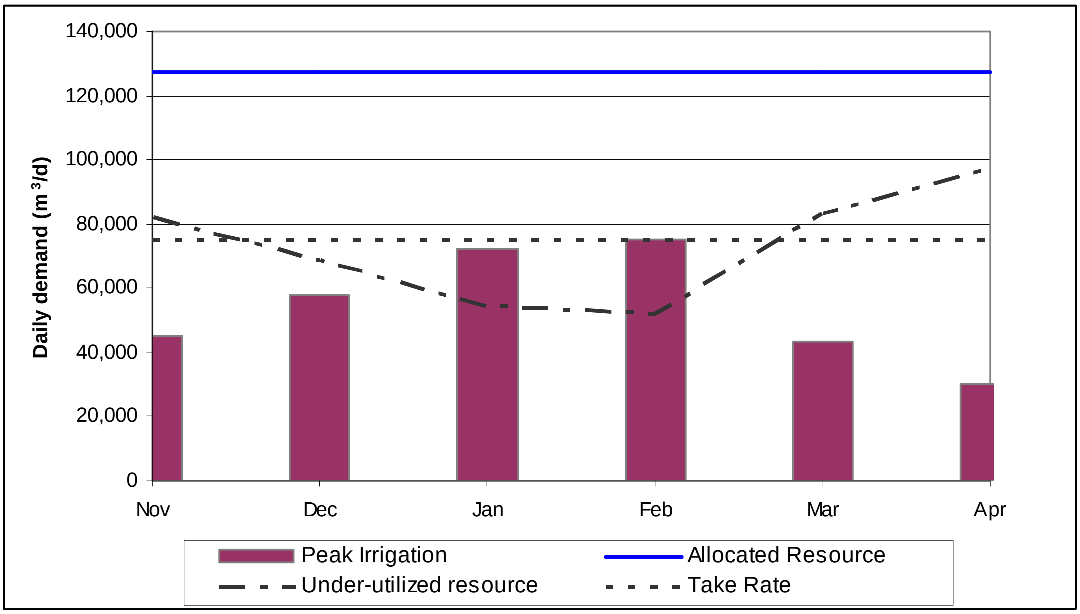

Figure 4: Water resource availability within current irrigation consents

4.3 Alternative Allocation Options

As discussed in the preceding sections, the surface water resources of the Waihou catchment are close to full allocation. Therefore, allocation efficiency is or will become an issue to improving water availability and water use efficiency (within current water availability criteria). As outlined above, allocation efficiency for irrigation takes is constrained by current allocation rules on take rates and by seasonal demand factors.

The series of points below list a range of potential actions to improve water use efficiency for irrigation takes. These are:

a) Make takes at a rate higher than the 24-hour (or a nominal irrigation day, i.e. 20 hours) and above a minimum threshold (for example 5 ℓ/s) conditional on the following:
   - Specification of take period per day (i.e. hh:mm to hh:mm);
   - Electronic logging of take to ensure compliance with take period and daily volume.

   The above measures provide verification of cumulative effects and allocation of resources outside the take period.

b) Specification of irrigation season as November to April, to establish the limits of the period within which the take days are allocated (retain the current take days, 90-120 days). The benefit being that the period of irrigation demand can be determined for evaluation of cumulative effects.

c) Establishment of stepped irrigation demand for the season margins (i.e. November-December and March-April), with cumulative daily allocation per month based on a percentage of peak demand (approximately 60% of maximum daily allocation). This would enable the allocation to meet complementary seasonal demand within the irrigation season margins such as for frost protection.

d) Establish a secondary class of take consents (B share), for either under-utilized allocations (for example seasonal irrigation takes) and/or allocations above current water availability criteria. The secondary take would be restricted at a higher flow threshold than current allocations (i.e. % above Q_5), and therefore be less reliable.

5 CONCLUSIONS

The principal conclusions for the study findings are summarised as:

a) System and seasonal irrigation efficiencies are reasonable, and consistent with those adopted under the Plan. They do not indicate any major issues of abnormally low efficiency of water use. However, they should be considered within the limits of the study and available information. Nevertheless, they are consistent with other issues regarding the cost and management of irrigation systems on dairy farms. Apart from the centre-pivot, all other systems (long-lateral, K Lines and travelling gun irrigators) are labour intensive, and therefore system operation is stopped when deemed to not be required. There are also other farm management issues, particularly the possibility of pugging, which discourage over-irrigation.

b) Irrigation demand values determined from modelling. Average and peak annual values of 300 and 380 mm are considerably lower than those currently adopted for the area (Netherton) in the Regional Plan. This is an issue worthy of further investigation as it may have an impact on future development of allocation options which establish seasonal and annual allocations, though it does not impact on daily allocation criteria that forms the basis for current irrigation consents (which are based on peak daily demand).

c) Water use efficiencies for dairy farms in the Waihou indicate that the marginal benefit of irrigation is approximately $300-400/ha dependent on system type and payout level. The returns to water are about 10 to 12 cents per cubic metre. These are comparable values to other parts of the Waikato Region.

d) Water allocation efficiency for irrigation is approximately 50% of the allocable volume. The principal constraint is the allocation of takes rates for short duration, which essentially reduces total allocation take by 600 ℓ/s. Should this take be available, it could support the development of approximately 1,100 ha of irrigable land with the financial benefit in excess of $400,000/y or the equivalent of $7 million in land values.

e) Alternative allocation options should look at mechanisms to maximise allocable resources. For irrigation takes this could include: take rates based on 24-hour duration, definition of irrigation season and associated peak monthly take volumes, and possibly the establishment of a secondary take category for the utilisation of complementary component of takes for other non-irrigation uses.

6 KEY ISSUES AND CONSTRAINTS

Key issue and constraints to the study include:

a) Pasture production; the assessment is based on average monthly values. However, this is likely to vary between seasons due to non-irrigation related factors (temperature) and between farm factors (fertiliser application, grass species etc).

b) Water use efficiency; the productive response based on average cow stocking rates and performance (i.e. stocking rates of approximately 3 per ha for non-irrigated properties, and 325 kg MS/cow/season). While this are based on average districts, there is like to be considerable variation between individual farms, dependent on a range of physical and financial factors.

c) Irrigation application uniformity; the assessment is based on an empirical approach (i.e. CU for sprinkler types). However, there are likely to be on site factors (wind, quality of system installation and maintenance). While it is beyond the scope of this study, direct on-farm system audits would provide further detail on application uniformity (design and management). However, as indicated in this study the greatest improvement in water use efficiency within the Waihou catchment can be achieved through improved allocation process rather than irrigation system performance.

d) Seasonal irrigation efficiency is constrained by availability of water use records. However, records are largely patchy with few complete data sets. This is an area EW is currently looking at improving.

e) Telemetry was not established as proposed at the start of the project, due to technical and associated financial constraints in installing equipment. The principal problem was the difficulty and cost of upgrading existing meter installations for digital output for logging and telemetry. This is a common problem with retrospective installation of telemetry systems on water meters. Thought should be given to identifying alternative metering options, to ensure the viability of the system (both technically and financially). One option is the installation of on-line impellers, which could be installed within existing headworks, or logging of a parallel factor such as pumping hours.

f) Accuracy of water use records is a constraint to accurate determination of farm irrigation efficiency. This needs to be improved if more accurate estimates of efficiency are to be developed. Options for improvement include logging with and without telemetry. The question is what level of reliability and accuracy is really required. For flow monitoring surface water needs to be daily, while for groundwater weekly or monthly is generally acceptable.

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Appendix A: Project objectives, methods and outputs

The project objectives, methods and outputs include the following:

Objectives
The principal objective is the determination of the efficiency of irrigation and water allocation in the Waihou catchment zone. This will be achieved via a set of specific objectives. These are:

- To determine the current levels of irrigation efficiency being achieved at farm and catchment levels.
- To determine the water use efficiency (kg/m^3 & $/$m^3$) for farm production systems.
- To identify key factors to the improvement of irrigation system performance and management and the potential impact on irrigation and water use efficiency.
- To determine current efficiency of use of agricultural water allocations within the catchment.
- To evaluate the impact of alternative allocation scenarios on resource availability and efficiency of resource allocation and use, and likely economic benefits.

Methods
The approach to the project will be based on the following methods and analysis:

1. Irrigation Efficiency Audit
   The analysis of irrigation efficiency will be based on the following elements:
   - Case study survey of a representative sample of farm and irrigation methods to determine system performance (application uniformity) and management.
   - Calculation of seasonal irrigation efficiency based on seasonal water balance (from modelled irrigation demand and actual water use (from water use records)).
   - Evaluation of irrigation efficiency from a sample (3-4 takes) of telemetry water use records during the current irrigation season. Actual use records will be compared to modelled water demand to determine efficiency.

2. Water Use Efficiency Analysis
   The determination of water use efficiency will be based on the following elements:
   - Seasonal water demand from modelling of time series irrigation demand.
   - Evaluation of the crop yield response to irrigation
   - Cost benefit analysis of the marginal response to irrigation for the farming systems.

3. Water Allocation Efficiency
   The assessment of allocation efficiency will be based on the following elements:
   - Assessment of peak and seasonal water demand (based on irrigation demand and irrigation efficiency).
   - Review of flow data for the Waihou river and tributary streams (on which takes are currently allocated).

4. Allocation Scenarios
   The assessment of the impact of allocation scenarios (potential changes in allocation rules and conditions) will be based on the determination of the impact of scenarios on resource availability (surface water). The assessment of the economic cost and benefit of scenarios will draw on water use efficiency data, as determined above.

Outputs

The project outputs will include the following:

- Estimate of application efficiency for the principal irrigation methods and farming systems within the catchment.
- Estimate of global (catchment) irrigation application efficiency and seasonal irrigation efficiency.
- Identification of key constraints to improving irrigation efficiency.
- Indicative irrigation water use efficiency values (kg DM/m^3, \$/m^3 and kg MS/m^3) for farm production systems.
- Estimates of global (catchment) allocation efficiencies.
- Estimates of changes in resource availability for allocation scenarios.
- Estimates of economic benefits associated with allocation scenarios.

The project outputs will be presented in report format, with supporting spatial information in Arcview format (Arcview project).

Appendix B: Summary of case farms

The table below presents a summary of the key farm details for the case study farms.

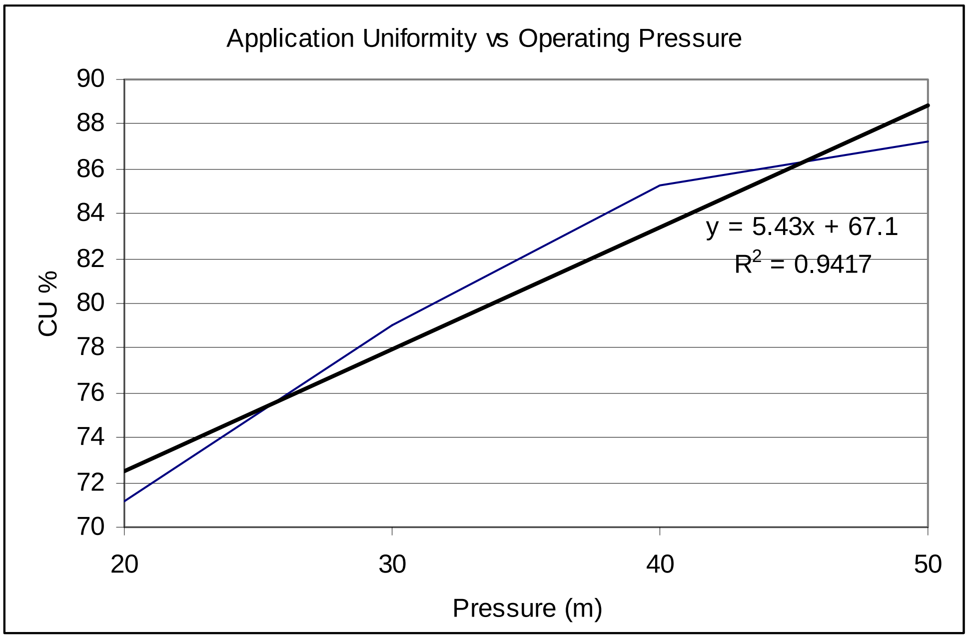
Farm No	Systems	Farm area (ha)	Effective area (ha)	Irrigated area (ha)	No of Cows	Cows/ ha	Milk solids (kg/y)	Milk solids (kg/cow/y)	Milk solids (kg/ha/y)
1	Gun	300	280	150	900	3.2	245,000	272	875
2	Long-lateral	117	112	112	370	3.3	120,000	324	1,071
3	Long-lateral	95	90	77	230	2.6	68,000	296	756
4	Gun	163	160	53	425	2.7	170,000	400	1,063
5	Long-lateral	100	90	60	300	3.3	100,000	333	1,111
6	Pivots (2)	317	271	93	1,485	5.5	480,000	323	1,771
6	Long-lateral	“	“	178					
7	Long-lateral	120	100	66	320	3.2	135,000	422	1,350
8	Long-lateral	80	75	75	250	3.3	80,000	320	1,067
9	K Line	82	80	62	300	3.6	102,000	340	1,275
10	K Line	80	75	75	270	3.6	89,000	330	1,187
Total/Average		**362**	**330**	**1001**	**1140**	**3.6**	**1,589,000**	**328**	**1,192**

Appendix C: Farm irrigation efficiency methods

The determination of farm irrigation efficiency is based on the following elements and steps.

a) ***Determination of Design Uniformity*** based on average sprinkler spacing and percentage of overlap, for which coefficient of uniformity (CU) and distribution uniformity (DU) were determined from manufacturers distribution tests.

b) ***System Uniformity*** based on calculation of pressure system operating pressure variations and determination of the area lower than design tolerance (i.e. less than 10% of nominal operating pressure). For these areas, a pressure uniformity relationship (approximately 2.5% reduction CU per unit pressure below design range) was applied to determine area and system CU.



c) ***Management Application*** Efficiency is the ratio of system mean application depth to modelled irrigation requirements. Ideally, when system capacity is matched to peak irrigation demand the AE will be close to 100%. If system capacity is lower than peak requirements the AE will be greater than 100%, indicating insufficient capacity to meet peak demand. This generally is a result of two factors: installed irrigated area is greater than that originally proposed for the system design, and/or lower than required take rate.

d) ***System Irrigation Efficiency*** The overall system application efficiency is calculated from the system uniformity and management application efficiency elements above. The system irrigation efficiency as a calculated value is indicative of the potential upper limit of system and management performance, during periods of high irrigation demand.

The table below presents a summary of the results for the surveyed irrigation systems.

Farm No	System	Design CU	System CU	Management IE	System IE
1	Gun	70	69	90	75
2	Long-lateral	79	78	82	71
3	Long-lateral	87	86	91	84
4	Gun	70	69	119	104
5	Long-lateral	79	78	101	90
6	Long-lateral	87	86	91	84
6	Pivot	87	87	91	85
7	Long-lateral	84	64	91	73
8	Long-lateral	79	74	91	78
9	K Line	79	77	91	79
10	K Line	79	64	248	230

Appendix D: Seasonal irrigation efficiency methods

The determination of seasonal irrigation efficiency is based on the following elements and steps:

Irrigation Demand

Irrigation demand for the 4-year period 2000-03 (period of water use records) was determined by modelling daily soil water balance. The model inputs included the following:

- Rainfall – daily rainfall depths for the Matamata station.
- Evapotranspiration (Penman) – no daily records were available for the Matamata station so daily ET values were used for Paeroa and Ruakura.
- Soil – while there were some variations in soil types between farms, most farms were Waihou series (silt loam and sandy loam) which have a profile readily available water content of 62 mm.
- Crop (pasture) – as the crop is a perennial crop the rooting depth was fixed at 0.5m. Based on grazed pasture management, the crop coefficient was fixed at 1.0 (assuming pasture height ranges between 10 to 30 cm under normal grazing regimes).
- Irrigation regime: the irrigation depth and frequency were 32 mm and 7 days respectively, with a CU of 70%.

The model outputs were:

- Soil moisture level (mm)
- Irrigation depth (mm).

The irrigation depth values formed the basis for determination of monthly and seasonal irrigation demand, calculated as equivalent volume per hectare times irrigated area per farm.

Water Use

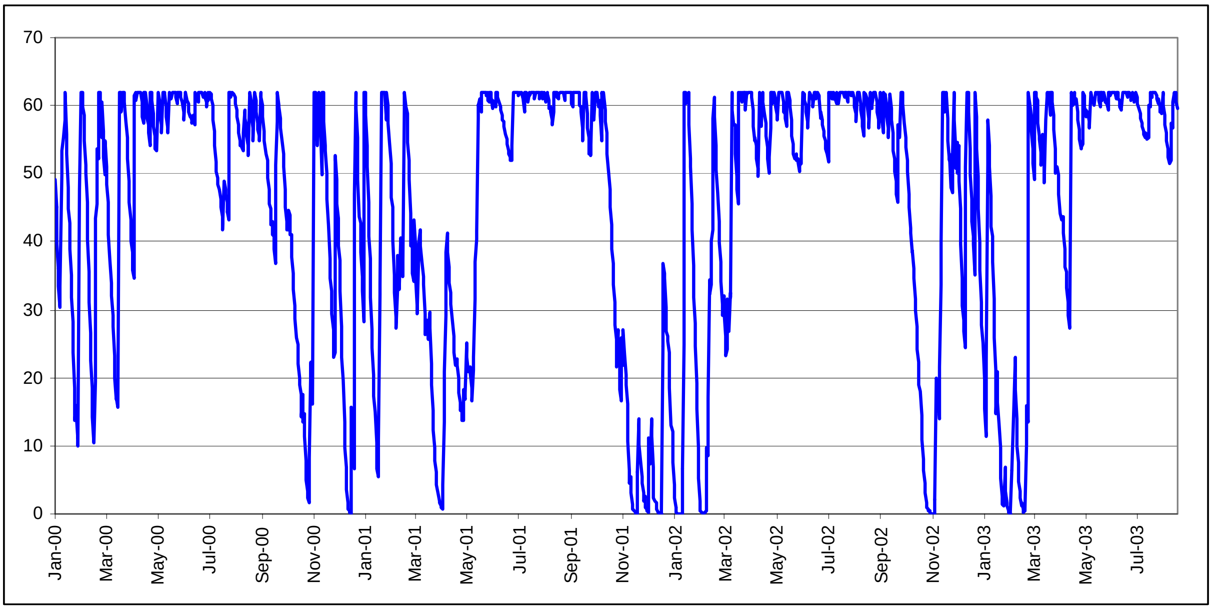
Environment Waikato provided a summary of current water use records for the 10 sample farms. The records listed daily volumes during the 4-year period 2000-03. In common with many similar situations manual recording of use is difficult to reliably enforce. The records are partial with some days in some years records for the farms. Nevertheless they are the best and most current records available.

Seasonal Efficiency

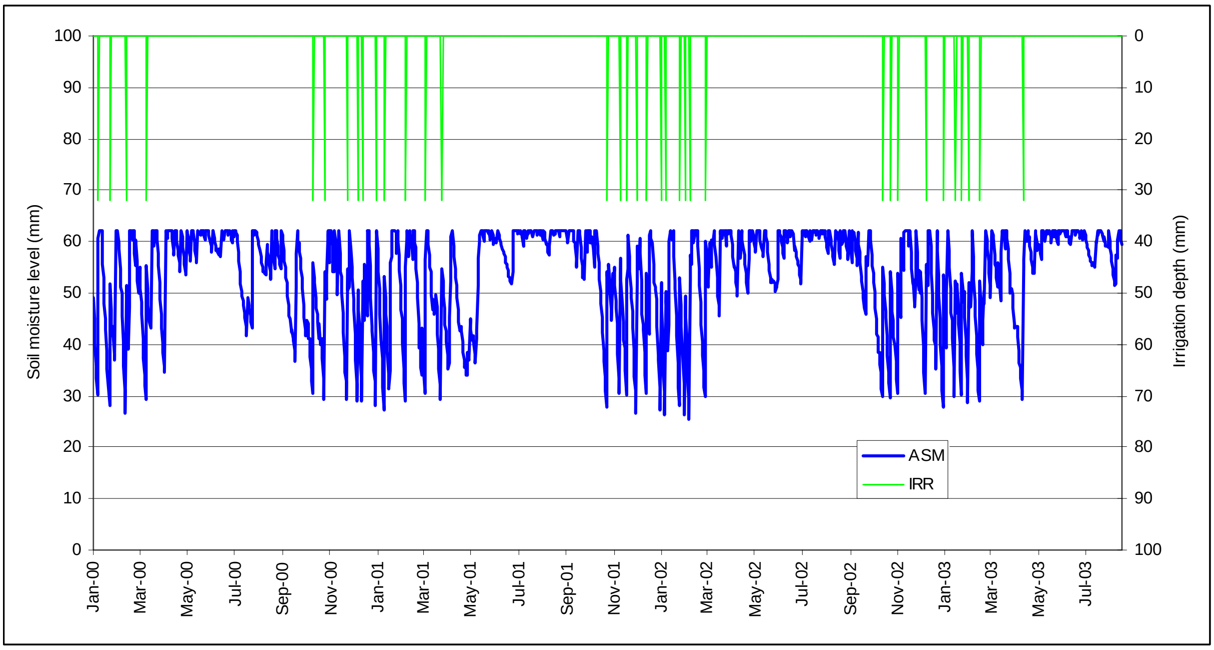
Seasonal irrigation efficiency is calculated as the percentage ratio of irrigation demand to water use. This was calculated on a farm by farm basis as the percentage ratio of modelled irrigation demand (for the months with water use records) to the actual use, as determined from the water use records.

The plots below show the non-irrigated and irrigated modelled soil moisture levels respectively over the period 2000-03. The irrigation requirements for the lower plot formed the basis for determination of farm irrigation requirements for seasonal irrigation efficiency.

Non-irrigated soil water plot



Irrigated soil water plot



ASM = Actual soil moisture level (mm)
IRR = Irrigation depth (mm)

Appendix E: Summary of seasonal irrigation efficiency values (%)

The table below presents a summary of seasonal irrigation efficiency for irrigation season (part A) and period of water use records (part B). The latter are generally lower due to the fact that most water use records were at best only reported for a part of each season.

Farm No	1	2	3	4	5	6	7	8	9	10
System	**Gun**	**Long-lateral**	**Long-lateral**	**Gun**	**Long-lateral**	**Centre-pivot /long-lateral**	**Long-lateral**	**Long-lateral**	**K Line**	**K Line**
Part A – Whole season										
1999-00 (4 mths)		52	77							
2000-01	266	103		284			137	1701		
2001-02	234	269		405		182	178	6322		
2002-03	251	98		455	330		146		390	446
Part B – Period of records										
1999-00		52	78							
2000-01	107	82		205			55	680		
2001-02		49		74		83	81	1149		
2002-03	151	59		318	132		58		156	178

Appendix F: Water use efficiency methods

The determination of water use efficiencies is based on the following elements and steps:

Irrigation Demand
Irrigation demand was determined by modelling of daily soil water levelled, as summarised in Appendix D.

Pasture Yield Response
Pasture yield response was determined on the following assumptions and methods:

- Mean monthly pasture production rates (kg DM/d) for well watered pasture in the Waikato. These values were derived from discussion with farmers, farm consultants and from published records; these values are listed below:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kg DM/ha/d	80	70	60	40	20	10	10	20	40	60	70	80

- Total annual pasture production for well irrigated pasture is 16,990 kg/ha/y.
- The yield response to irrigation is based on the yield response to moisture stress (from the above daily model results) expressed in the equation below:

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

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 (kg DM/d)

Appendix G: Cost benefit analysis – approach, parameters and assumptions

The approach to the evaluation of the analysis of the financial costs and benefits of irrigation in the Waihou catchment is based on a generic farm model. The model is based on typical stocking rates, production levels and farm expenses in the Waikato. The model provides an indication of the comparative costs and benefits of irrigation on farm productivity and returns. It 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 (2.6 cows) and production level (295 kg MS/cow) with average district values (LIC, 2003).

ii) A pasture production response of 4,000 kg DM/ha is assumed as the average annual response to irrigation. This level of production is derived from the simulation of pasture yield over the period 1980-2003.

iii) Pasture production benefits are allocated according to the following criteria:
- 35% 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 priced at a rate of $0.10 per kg DM.
- 50% of the yield is converted to an increase in stocking rates at conversion rate of 3,900 kg DM/cow (DM consumption during the milking season), typically this is an increase in stocking rate of 0.4 cows/ha.
- 15% of the yield is converted to an increase in per cow milk solids production at the rate of 15 kg DM per kg MS, typically this is an increase of approximately 60 kg MS/cow

iv) Annual irrigation volume - the average annual irrigation demand is 300 mm equivalent to 3000 m^3/ha.

v) Irrigation costs are based on the following:
- System capital costs are based on typical values for the study farms.
- 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.

- Operating costs are based on:
  - o Energy costs comprising of both fixed and consumption charges as listed below:
    - Fixed charges (based on typical motor duty)
    - 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.

- o Operation and maintenance costs are based on percentage (2-5%) of above system components.
- o Labour costs are based on average daily labour requirements (system specific) at an hourly 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 following tables summarise the cost analysis for the four principle irrigation systems and the sensitivity to payout level.

Cost analysis:

Description	Irrigation system			
	K Line	**Long-lateral**	**Centre-pivot**	**Gun**
Irrigation uniformity (%)	70	70	80	70
Stocking rate (cows/ha)	3.2	3.2	3.2	3.2
MS production (kg MS/cow)	335	335	335	335
MS production (kg MS/ha)	1,056	1,056	1,056	1,056
MS return ($/kg MS)	4.20	4.20	4.20	4.20
Total income	4,767	4,767	4,767	4,767
Farm working expenses	2,385	2,385	2,385	2,385
Irrigation expenses	550	502	461	477
Total expenses	2,935	2,888	2,846	2,863
Cash surplus	1,832	1,879	1,921	1,904
Total adjustments	-662	-662	-662	-662
Economic farm surplus	1,170	1,217	1,259	1,242
Marginal benefits ($/ha)	291	338	380	363
Net returns to water ($/m^3)	0.10	0.11	0.13	0.12
Cost $/kg DM	0.14	0.13	0.12	0.12

Payment sensitivity:

Payout ($/kg MS)	**Marginal benefits ($/ha)**	**Water returns ($/m^3)**
3.2	-718	-0.24
3.4	-507	-0.17
3.6	-296	-0.10
3.8	-84	-0.03
4.0	127	0.04
4.2	338	0.11
4.4	549	0.18

Appendix H: Summary of current consented takes and consent applications

The table below is a summary of surface water take consents for the Waihou catchment, as supplied by EW. The consents are grouped by principal use category, and reported by number, cumulative take rate (l/s), daily volume (m^3/d) and annual volume (Mm^3/y).

Use	Consents		Take rate		Take volume		Annual volume	
	No	**%**	**ℓ/s**	**%**	**m^3/d**	**%**	**Mm^3/y**	**%**
Farm supply	6	9	7	0.3	395	0.3	0.04	0.2
Fish farming	2	3	3	0.1	180	0.1	0.02	0.1
Industry	8	12	267	10	21,511	14	2	6
Irrigation	31	45	1,471	58	75,098	49	10	39
Water supply	22	32	796	31	56,437	37	14	55
Total	**69**		**2,544**		**153,621**		**25.66**	