Optimisation of Farm Irrigation

PREPARED FOR
TARANAKI REGIONAL COUNCIL

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List of Abbreviations

DM	dry matter
ha	hectare
kg	kilogram
km/hr	kilometres per hour
l/s	litres per second
mm	millimetre
m	metre
MS	milk solids
Paw	profile available water
Praw	readily available water
PET	potential evapotranspiration

List of Acronyms

TRC	Taranaki Regional Council
NIWA	National Institute of Water and Atmosphere
LE	Lincoln Environmental
NZLRI	New Zealand Land Resource Inventory
CSMM	Conceptual Soil Moisture Model

EXECUTIVE SUMMARY

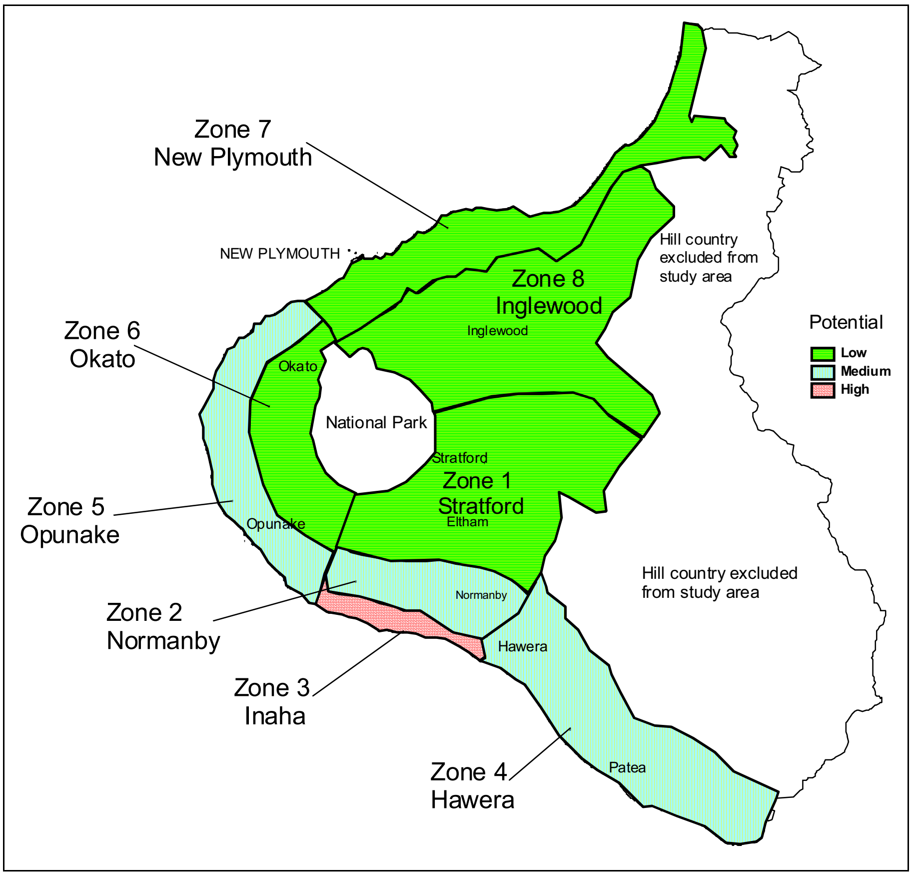
In the Taranaki region, the recent increase in the number of irrigation consent applications highlights a number of issues related to water allocations and future demand for water resources. This study was commissioned by the Taranaki Regional Council to evaluate irrigation and water demand within the region, and to identify those areas where irrigation development is most likely to occur in the future.

The study area encompassed an area of approximately 378,000 ha, encircling Mt Egmont and the coastal plains to the south and north. The predominant land use within the area is dairy farming. Irrigation development within the area is almost exclusively for pasture production for rotational grazing and supplementary feed conservation.

Study information sources and methods included:

- Soil water balance model; for determination of irrigation rates and water allocation for major climate zones and soil types.
- Pasture production response analysis to irrigation
- Consultation with farmers and irrigators within the region
- Review of literature related to irrigation methods and costs
- Farm consultant support from local Farmwise consultant Mr. M Joyce
- Analysis of irrigation costs and benefits to identify financial drivers for irrigation development

Irrigation Zones: The water balance model results form the basis for the classification of irrigation zones (8) in the figure below. The zones reflect the rainfall pattern and soil type distribution within the study area.



***Irrigation Rates and Water Allocations**:* The table below lists a summary of irrigation rates and water allocations for the eight irrigation zones. Variations in irrigation rates relate to differences in the rainfall intensity and frequency and soil waterholding characteristics between zones. Likewise, these factors influence the daily allocation and take rates for the zones. The season allocation is based on the highest annual irrigation requirements recorded over the modelled period (16-22 years).

Zone No.	Irrigation Rate		Water Allocation		
	Depth (mm)	Interval (d)	Daily (m^3/d/ha)	Take Rate (l/s/ha)	Season (m^3/ha/yr)
1	44	14	31	0.40	2,200
2	44	11	40	0.51	4,840
3	32	7	46	0.58	6,400
4	32	6	53	0.67	5,120
5	30	6	50	0.63	4,200
6	30	6	50	0.63	3,600
7	50	12	42	0.53	4,000
8	44	12	37	0.46	3,960

***Irrigation Systems**:* Listed below is a summary of systems used in the region, along with benefits and constraints.

- K-lines; relatively low capital cost, low application rates, suits farm layout, high labour and maintenance requirements.
- Long lateral; low capital cost, suits existing farm layout, high application depths and long return intervals.
- Centre pivot; high capital cost, versatile operation and low labour requirements.
- Travelling irrigators; constrained by farm layout and performance affected by high wind.

***Irrigation Efficiency**:* For the purposes of this study, application efficiency is the most appropriate definition of irrigation efficiency, which is the ratio of applied water to water retained within the crop root zone. Uneven or excessive application depth accounts for up to 30% of water losses from sprinkler and spray systems. In Taranaki, wind is a key factor affecting application uniformity, with average wind speeds ranging between 12 to 20 km/hr over the irrigation season (Nov-Apr). System design and management needs to take into consideration the frequency of high winds, with a reduction in sprinkler spacing to maintain application uniformity.

***Pasture Production and Utilisation**:* Yield response of pasture to irrigation of more than 2,000 kgDM/ha/yr is predicted for the four zones with the highest annual water demand (2, 3, 4 and 5). This additional production is utilised through increases in stocking rates, by up to 0.6 cows per hectare (with consequent increase in milk solids production) and greater supplementary feed conservation. The potential for pugging under irrigation is likely to be low, for well managed systems, though the risk increases for systems with low uniformity. There is unlikely to be significant (relevant to irrigation management) change in evapotranspiration and therefore irrigation demand under rotationally grazed irrigated pasture.

Irrigation Costs and Benefits: The table below lists the marginal return to irrigation on a unit area and unit volume basis. There are negative returns for four zones (1,6,7 and 8), indicating that there is a likely to be a low financial incentive to invest in irrigation. One zone has a marginal return greater than $200/ha (zone 3) and the remaining three are between 38 to 132 $/ha.

Sensitivity analysis indicates that the zones with low returns (zones 1,6,7 and 8) are relatively insensitive to variations in milk solids returns, primarily due to the low yield response to irrigation. Those zones with high returns show a positive response over a wide range of returns that is irrigation remains a financially attractive option.

Zone no.	Marginal Return ($/ha)	Return to water ($/m^3)	Development Potential
1	-205	-0.14	Low
2	92	0.03	Medium
3	236	0.05	High
4	132	0.04	Medium
5	38	0.01	Medium
6	-92	-0.05	Low
7	-76	-0.03	Low
8	-204	-0.10	Low

Development Potential*:* Based on the yield response and marginal returns the study area was classified into three categories of irrigation development potential, as indicated in the above table. Zone 3, the area around Inaha and Manaia, is classified as of high potential, and the surrounding zones (2,4 and 5) are of medium potential. The inland and northern zones (1,6,7 and 8) have low development potential.

1 INTRODUCTION

This report presents the findings and recommendations of a study of irrigation in the Taranaki region of New Zealand. It was commissioned by the Taranaki Regional Council (TRC) to investigate current and potential irrigation development and to provide information relevant to the management of water resources within the region.

In the past decade, the irrigated area in New Zealand increased by 80% from 300,000 to more than 500,000 ha (MAF, 2002). Much of this expansion occurred on the drought prone eastern provinces of both the North and South Islands from Otago to Hawkes Bay. Irrigation was adopted to increase productivity, and often associated with land use changes from arable to dairy farming.

The Taranaki region has largely been regarded as a "wet" province, with sufficient and regular rainfall to maintain summer and autumn pasture production. This is illustrated by national statistics, which as late as 2002, do not list an irrigated area for the region (MAF, 2002). However, at least two irrigation schemes have previously been considered within the region. In the late 1990's there was renewed interest, with Taranaki Regional Council records showing that resource consents have been issued for a total irrigated area of more than 2,500 ha, almost exclusively for irrigation of pasture on dairy farms.

Irrigation development within the region to date has largely been based on access to surface water. This is often the most easily accessible and lowest cost option while allocatable resources are available. However, catchments are relatively small and therefore allocatable take rates are likely to be limited. In planning for and managing water resources within the region, it is important to better understand current and future irrigation demand to enable more informed decisions on resource allocations.

The following sections present an outline of the project including objectives, study area, methods and information and data sources. The findings are presented in a series of related sections; (i) assessment of irrigation demand and subregional irrigation zones, (ii) review of irrigation systems, (iii) evaluation of irrigation responses, (iv) irrigation cost-benefit analysis, (v) classification of irrigation development zones and (vi) conclusions and discussion.

1.1 Previous Work

The relatively recent development of pastoral irrigation in Taranaki means there is limited literature on the specific response to and benefits of irrigation in the region. However, dairy farming has been the predominant land use within much of the region and particularly within the study area, for over 100 years. Therefore there is a significant body of information related to pasture production, some of which refers to the relationship between production and rainfall and/or periods of drought.

At least two community irrigation schemes have been considered in Taranaki. In the early 1970's a scheme was proposed for irrigation of pasture on farms at Inaha in South Taranaki (Dean, 1974). The proposed scheme encompassed 20 farms, predominately factory supply dairy farms, with an irrigable area of over 1,000 ha. Analysis of soil water balances for a 15 year period indicated that average to severe droughts (that is more than 20 days of "soil dryness") occur in more than 50% of milking seasons.

In the early 1980's a community irrigation scheme was proposed for up to 360 ha at Oakura, south of New Plymouth (Wilson, 1984). The scheme was primarily aimed at prospective horticultural development, in particular possible development of kiwifruit orchards in the area. It is interesting to note that local dairy farmers opposed the scheme based on concerns over land use changes within the scheme area. The soil water balance for the area for the period 1971-84 indicated that on average there are 42 deficit days per year (based on soil readily available water of 70 mm).

In 2002 a paper was presented at the Annual Dairy Farmers Conference reporting on the adoption of irrigation on a dairy farm near Patea (Horne et. al, 2002). The system consists of five centre-pivots irrigating a total area of 120 ha, of which 85 ha is on low waterholding Patea sand adjacent to the coast. The motive for the adoption of irrigation was based on the ability to increase pasture production and consistency of yield between seasons. This was translated into improved financial returns and appreciation of land values. During the 2000-01 season, a very dry summer, it is estimated that irrigation produced an additional 7,200 kg of dry matter per hectare (kgDM/ha). On average, under normal rainfall conditions, it predicted that the system results in an additional 4,000 to 5,000 kgDM/ha of pasture production. At these production levels the cost per unit of dry matter is calculated at 6c per kgDM, which compares with 12c per kgDM for alternative supplementary feed options.

The primary objective for adopting irrigation for pasture in the region is to increase pasture production during periods of soil moisture deficit. Pasture production is dependent on a number of conditions, including soil water availability, fertility and temperature. In Taranaki pasture production is influenced by proximity to Mt Egmont (Brown et al, 1989), principally due to the influence of rainfall and soil temperatures. While total annual production is similar between locations, there are seasonal variations between coastal and higher altitude inland locations due to differences in temperature and rainfall. Coastal locations show distinct seasonal peaks in spring and autumn, with a drop in pasture growth over summer due to soil moisture stress.

While the above studies provide an indication of potential for irrigation development in the region, to date there appears to have been no specific research evaluating the productive and financial response to irrigation. Therefore the analysis of productive response presented in this report is largely dependent on correlation of known pasture response with calculated soil water deficit over the year(s) for which the data was recorded. Where data is available this approach appears to match reasonably well with typical production levels reported for the various locations within the region.

2 PROJECT DESCRIPTION

The project was initiated by the Taranaki Regional Council to provide information related water resource management in the agricultural sector. As indicated above, there has been a considerable expansion of the irrigated area in recent years. There is a need to better understand irrigation requirements as the basis for water allocations and to identify the areas where future irrigation development is likely to occur.

This section presents an outline of the project; objectives, study area, outputs and approach and structure of this report.

2.1 Objectives

The project objectives were:

1. To undertake research that provides Taranaki Regional Council with information on how to manage the allocation of water for pasture irrigation purposes. Specific objectives include:
    - Appropriate application rates for Taranaki climate and soils
    - Appropriate irrigation systems
    - Appropriate grazing regimes.

2. To identify areas of the Taranaki region suited to irrigation based on soil type, climate and economic factors. Specific objectives include:
    - Review of irrigation costs, capital and operating.
    - Cost–benefit analysis of irrigation for pastoral farming systems in the region.
    - Identification of areas suitable for irrigation based on economic benefits.

2.2 Study Area and Farming Systems

For purposes of this project, the study area is defined as those areas within the region that, based on topography, soil type and land use, are suitable for irrigation. The area was identified from the New Zealand Land Resource Inventory (NZLRI), based on land use and topography classifications (Newsome et al, 2000). Figure 1 shows the study area which comprises an area of approximately 375,000 ha, encircling Mt Egmont and coastal areas to the north and south. Approximately 280,000 ha of the area is classified as farmed, most of which is in dairying.

2.3 Outputs

To achieve the above objectives the project outputs include the following:

i) Irrigation demand (application depths and return intervals) for the main climate and soil zones.
ii) Peak and seasonal water allocation rates (cubic metres per hectare per day (m^3/ha/d) and cubic metres per hectare per year (m^3/ha/yr) respectively) for the main climate and soil zones.

iii) Evaluation of suitability of irrigation systems for use in the region and identification of the factors that influence system performance and efficiency.

iv) Review of irrigation system costs, including capital and operating costs.

v) Evaluation of the relationship between grazing practices and irrigation management, including the impact on evapotranspiration, pasture availability and potential for pugging under irrigation.

vi) Evaluation of the costs and benefits of irrigation for dairy farming in the region.

vii) Classification of the principal areas with potential for irrigation development based on physical and economic factors.

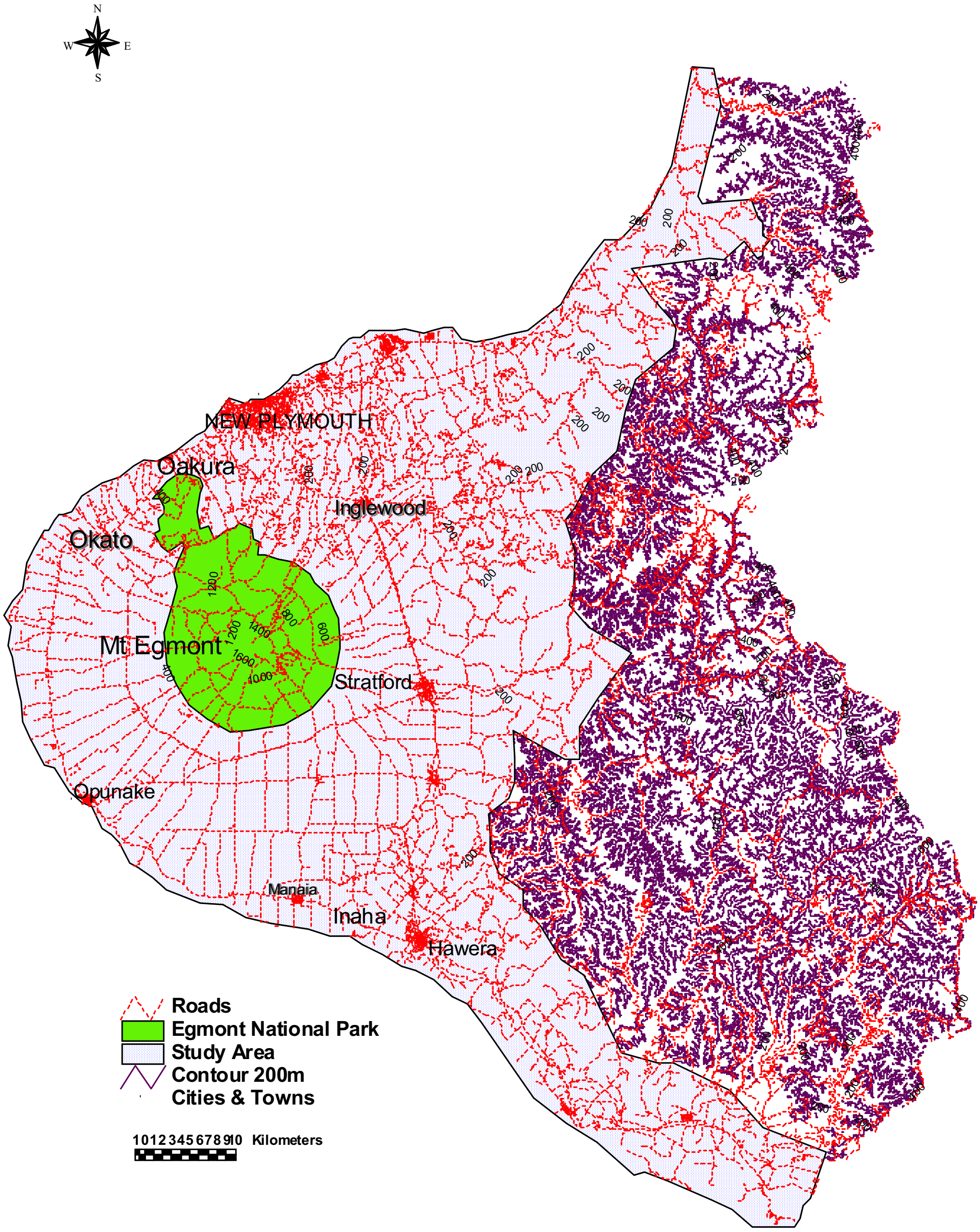


Figure 1: Taranaki region and study area

2.4 Approach

The project was primarily a desktop study utilising a variety of information sources and analytical methods. These included:

- Field visit: visit to the region to meet with a selection of farmers (six) currently using irrigation to discuss issues associated with the adoption and management of irrigation. The visit was conducted over a two-day period and involved meeting with farmers on site. The range of systems included k-lines, long laterals and centre pivots.
- Climate data: collation of rainfall, PET and wind data from NIWA and TRC databases
- Irrigation systems: information provided by TRC on current resource consents and related irrigation systems.
- Farm consultant: utilisation of the services of a local farm management consultant (Farmwise) Mr. Michael Joyce, to provide information and feedback on farm management issues. Mr. Joyce has extensive experience with dairy farm management in Taranaki. He has recently been involved with an irrigation development on a property near Manaia.
- Research: review of research and literature related to the irrigation and pasture production in the Taranaki region.
- Analysis: adoption of models and analytical methods for analysis of soil water balances, pasture production and financial costs and benefits of irrigation. The specific methods adopted are further discussed within the relevant sections and associated appendices.

2.5 Report Outline

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

- Section 3.0: Irrigation rates and water allocations; methods and results for analysis of irrigation requirements and water allocations.
- Section 4.0: Irrigation systems; review of irrigation systems, factors influencing system efficiency and system costs (capital and operating).
- Section 5.0: Pasture production and grazing management; pasture production response to irrigation, pasture utilization and grazing management issues.
- Section 6.0: Irrigation costs and benefits; evaluation of costs and benefits of irrigation for main climate and soil zones.
- Section 7.0: Irrigation development zones; classification of potential development zones.

3 Irrigation Rates and Water Allocations

This section presents an outline of the methods and results of the evaluation of irrigation rates and water allocations.

3.1 Water balance method

The fundamental approach to the determination of irrigation rates and water allocations is based on a computer water balance model to obtain the relationship between irrigation rates and the percentage of time that full crop water demand is satisfied. This relationship is based on an acceptable level of reliability of supply that meets crop water demand most of the time and is economically feasible for system design.

The conceptual soil moisture model (CSMM) was used to calculate the daily soil water balance. The model was developed by Lincoln Environmental for the analysis of the response of soil water levels to various irrigation options. A description of the model and its simplifying assumptions is given in Appendix A.

The model was used to evaluate two scenarios for each location, these were:

- Soil moisture levels without irrigation (current non-irrigation scenario)
- Soil moisture response to irrigation at specified application depth and return period (within acceptable criteria, as listed below).

For irrigation of pasture it is uneconomic to design systems to meet the absolute maximum crop water demand. The design objective is to ensure production levels are maintained close to maximum levels for most of the time. Therefore the determination of an acceptable irrigation rate (irrigation depth and return interval) was based on probabilistic frequency of soil moisture levels as listed below:

- The absolute minimum daily soil moisture level was set at 25% of the profile readily available water (Praw) (as defined below)
- The lower percentile allowable daily soil moisture level (i.e. the soil moisture level is wetter than this 95% of the time) was set at 50% of the Praw (i.e. the normal irrigation trigger level).

Primary inputs for the model include climate (daily rainfall and potential evapotranspiration) soil (available water capacity), crop (crop type, rooting depth and evapotranspiration factors) and irrigation parameters (applied depth, timing and performance). The model outputs include daily soil moisture levels, actual evapotranspiration, application depth and soil drainage.

The crop was pasture for which it was assumed the crop coefficient (Kc) was 1.0, that is, grass cover was complete throughout the year and the rooting depth was constant at 0.5 metres. The irrigation rate is based on an application uniformity (CU) of 70%, which is typical for many sprinklers systems in New Zealand under field conditions.

3.2 Site Selection

One of the purposes of the study is to evaluate the spatial differences in irrigation rates and water allocations for the definition of irrigation zones. The evaluation of spatial distribution is limited by the availability of climate records of daily rainfall and potential evapotranspiration (PET) of sufficient duration. As indicated below, long-term records (greater than 15 years) daily rainfall were available at eight locations and for PET at three locations. These records, plus extrapolated values for PET, form the basis for the determination of irrigation rates and water allocations presented in Sections 3.3 and 3.4.

3.2.1 Rainfall and potential evapotranspiration

The frequency and intensity of rainfall determines the levels of recharge to the soil and potential evapotranspiration provides the basis for evaluation of crop water demand.

Long term daily rainfall records were available for a number of locations within the study area monitored by NIWA and TRC as shown in Appendix B. The essential criteria in selection of locations was existence of a data set with time series spanning 15-20 years. Table 1 shows the selected locations along with duration of rainfall and climate records.

Rainfall patterns in the region are largely influenced by Mt Egmont, with annual rainfalls from approximately 1,000 mm near the coast to more than 8,000 mm at the summit (2,500 masl). Within the study area mean annual rainfall varied between areas, from more than 2,000 mm at Stratford to just over 1,000 mm at New Plymouth and Inaha.

Table 1: Rainfall and Climate Stations

Location	Data		Time Series	
	Rainfall	PET	Period	Years
New Plymouth	·	·	1980 - 2001	22
Tarata	·		1980 - 2001	22
Stratford	·	·	1980 - 2001	22
Normanby	·	·	1985 - 2001	16
Inaha	·		1985 - 2001	16
Hawera	·		1985 - 2001	16
Patiki	·		1985 - 2001	16
Kahu	·		1985 - 2001	16

Potential evapotranspiration was calculated on a daily basis using the Penman-Monteith method. The climate inputs are; air temperature, wind speed, solar radiation and vapour pressure. Climate parameters of more than 15 years duration were available for three stations at New Plymouth, Stratford and Normanby as indicated in Table 1. Mean annual PET ranged from 976 mm at New Plymouth to 745 mm at Stratford. Long term climate records were also available for a station located at Wanganui to the south of the study area. For locations along the coast, from Patea to Otako, daily PET was extrapolated from the relationship between values for the stations located at Normanby and Wanganui. On this basis PET along the coast is estimated to be approximately ten percent higher than those recorded at Normanby. For the inland area around Inglewood, between New Plymouth and Stratford, daily is estimated to be approximately 15 percent lower than values recorded at New Plymouth.

Table 2: Summary of Annual Rainfall and PET

Location	Rainfall		PET	
	Annual	Std Dev	Annual	Std Dev
New Plymouth	1,042		976	37
Tarata	1,695		830[1]	
Stratford	2,012		745	33
Normanby	1,109		843	109
Inaha	1,025		928[2]	
Hawera	1,168		928[2]	
Patiki	1,332		928[2]	
Kahu	1,912		843[3]	

Notes: (1) PET 15% lower than New Plymouth
(2) PET 10% higher than Normanby
(3) PET equal to Normanby

3.2.2 Soil Types

For this study the identification of the principal soil types and their associated waterholding characteristics is based on information derived from the New Zealand Land Resource Inventory (NZLRI) (Newsome, 2000). The NZLRI is a national soil information database, which provides information on the spatial distribution of soil series and types, along with descriptions of structural and textural characteristics.

The most important physical characteristics relevant to irrigation are those related to soil waterholding capacity, drainage and effective plant rooting depth. The NZLRI defines soil water available for plant growth as the profile readily available water (Praw) which is estimated from the volumetric water content difference between –10 kPa and –1500 kPa in the 0-0.4 m layer, and between –10 kPa and –100 kPa in lower layers (Webb et al, 1995). The predominate soil types within the study area do not have limitation on soil drainage or planting rooting depth within an effective rooting depth of 0.5 m (the adopted value for this study).

Apart from the coastal sand (Castlecliff and Himitangi sands), the Praw are moderate to high. Soils (Egmont brown loams) to the south and east of Mt Egmont have a Praw of between 76-100 mm with an area of lighter soils (Egmont black loams) with Praw of 50-75 mm located in a strip along the coast near Inaha and Manaia. On the south-west flank of Mt Egmont, Praw varies between 50 to 100 mm due to the variety of soil types associated with the lahar formations. Around New Plymouth and to the north along the coast, Praw values are within the range of 100-125 mm. Table 3 lists the soil types and Praw values adopted for analysis in the soil moisture balance.

Table 3: Praw of soils adopted in study

Soil Series	Soil Type	Praw (mm)
New Plymouth	black loam	112
Stratford	fine sandy loam	87
Stratford	coarse sandy loam	62
Stratford	sandy loam	87
Egmont	black loam	62
Egmont	brown loam	87
Castlecliff	sand	24
Punehi	series	62
Opua	series	62
Rahuto	series	62
Awatuna	series	62
Inglewood	coarse sandy loam	87

3.3 Irrigation Rates

The soil water model was used to assess irrigation rates for the eight sites with long term rainfall and PET records as outlined above. This assessment was based on predominate soil type within the immediate vicinity of each site. Appendix E shows the plot of the frequency of soil moisture levels for non-irrigation and irrigation for the eight sites that meet an acceptable probabilistic frequency of soil water levels (Section 3.1).

The irrigation rates, that is, application depth and return intervals, for the eight sites are presented in Table 4. These sites form the basis for the derivation of irrigation zones within the study area as discussed below. It should be noted that application depth is expressed in millimetres of irrigation, this is the gross irrigation depth per cycle based on an application uniformity of 70% (Section 3.1). The table lists mean and maximum annual application depths (mm). The return interval is expressed in days for completion of the irrigation cycle.

Figure 2 presents the proposed irrigation zones within the study area, this classification is derived from the assessment of irrigation rates and rainfall and soil distributions (primarily Praw). Eight irrigation zones are identified, four inland (zones 1, 2, 6 and 8) and four coastal (zones 3, 4, 5 and 7). The derivation of the zones assumes a number of simplifications, such as being based on predominate soil type and on data from a limited number of rainfall stations. This classification forms a useful starting point for further evaluation of irrigation demand and water allocations.

Table 4: Irrigation application depths and return intervals

Zone No.	Zone Name	Application Depth (mm)	Return Interval (d)	Mean Annual (mm/yr)	Max Annual (mm/yr)
1	Stratford	44	14	142	220
2	Normanby	44	11	283	484
3	Inaha	32	7	438	640
4	Hawera - Patea	32	6	370	512
5	Opunake	30	6	334	400
6	Okato	30	6	189	390
7	New Plymouth	50	12	259	400
8	Inglewood	44	12	196	528

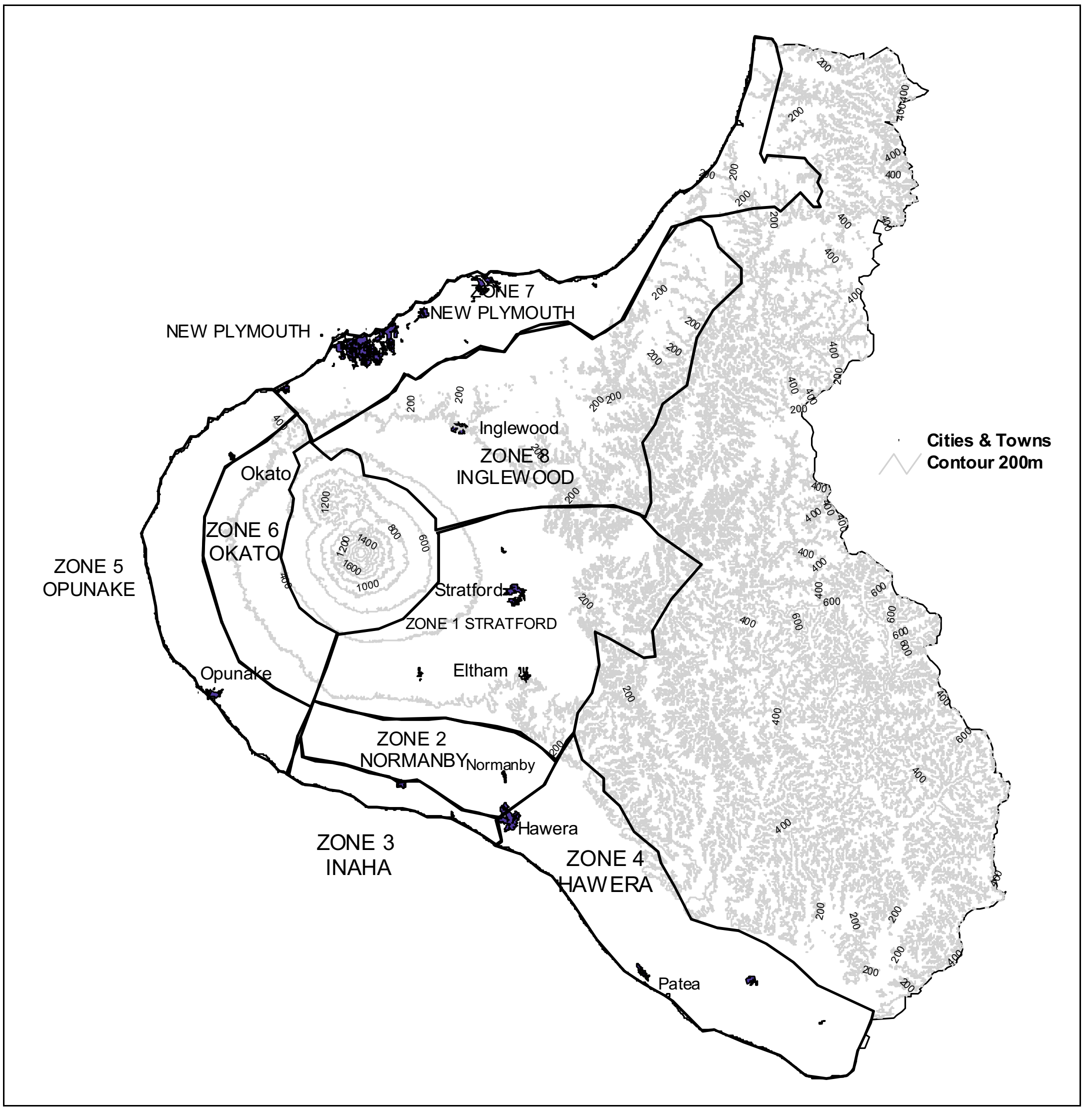


Figure 2: Irrigation zones

3.4 Daily and Seasonal Irrigation Allocations

Peak daily and seasonal water allocation are derived from evaluation of irrigation demand (Section 3.3). Table 5 lists the daily and seasonal irrigation allocations for the eight irrigation zones. Daily allocations are expressed in both volumetric (m^3/ha/d) and take rate (l/s/ha) terms. The take rate is based on the irrigation system operating for up to 22 hours per daily. Seasonal allocations are based on peak annual demand (over the modelled period), and are expressed volumetrically (m^3/ha/yr).

Table 5: Daily and seasonal allocations

Zone no.	Zone name	Daily allocation		Seasonal
		Daily (m^3/d/ha)	Take rate (l/s/ha)*	m3/ha/yr
1	Stratford	31.4	0.40	2,200
2	Normanby	40.0	0.51	4,840
3	Inaha	45.7	0.58	6,400
4	Hawera	53.3	0.67	5,120
5	Opunake	50.0	0.63	4,200
6	Okato	50.0	0.63	3,600
7	New Plymouth	41.7	0.53	4,000
8	Inglewood	36.7	0.46	3,960

Appendix G lists a summary of the key parameters and results for the derivation of take rates and daily and seasonal allocations.

Variations in take rates between zones largely reflect difference in soil waterholding capacity and irrigation demand. Rates are higher for zones with low waterholding soils and high crop water demand.

4 Irrigation Systems

In New Zealand a variety of irrigation methods have been adopted for irrigation of pasture. Historically these were largely based on border-strip, centre-pivot and travelling irrigators. During the 1990's two new systems were adopted: K-lines and long lateral, largely to meet the need of dairy farming for a low cost and versatile system. This section presents a summary of irrigation systems currently used in the region, an outline of system suitability for the range of operating conditions experienced in Taranaki, factors affecting efficiency and system costs.

4.1 Existing Systems in Taranaki

The TRC records indicate that to date, 45 consents have been issued for water takes for irrigation of dairy farms. Table 6 presents a summary of system types, numbers and irrigated areas for these farms. K-lines account for approximately forty percent of the known systems in number and area, with long-laterals, travelling irrigators and centre pivot with similar irrigated areas (approximately 250 ha). The predominance of k-lines and long laterals is largely due to the lower capital cost and suitability of these systems for installation for existing farm layouts. The system type was not specified for approximately a third of the consents.

Table 6: Summary of irrigation systems in Taranaki

System	Count	Volume (m3/d)	Take (l/s)	Area (ha)
Flood	1	12,960	150	112
k-line	12	21,785	367	684
Long lateral	4	8,721	148	256
Travelling irrigator	6	6,972	112	180
Travelling irrigator + k-lines	2	5,964	88	74
Centre pivot	4	12,700	236	248
Other	2	1,172	83	92
Subtotal	31	70,274	1184	1646
Not specified	15	41,443	533	995
Total	**45**	**98,757**	**1,567**	**2,641**

Note there are a range of travelling irrigator types, the difference being a function of the type of application device, such as rotary and fixed booms and spray guns.

4.2 Irrigation System Types

The selection of an irrigation system for a particular application is dependent on a number of physical, environmental and financial criteria. These include the following:

- Water availability
- Soil type
- Topography
- Operating conditions - wind
- Crop type & water demand
- Farm and paddock layout
- Labour requirement
- Capital cost
- Energy requirements

While surface irrigation has been extensively used in other parts of New Zealand, particularly in Canterbury and Otago, it is unlikely (apart from a few specific cases) to have a general application in Taranaki due to limitation of resource availability and topography. Pressure irrigation systems, mainly based on sprinklers and spray, are mostly likely to be best suited to the range of conditions experienced in the region as indicated by the range of existing systems. Ultimately the selection of a particular system for an application is dependent on a combination of factors, which includes a trade-off of cost with labour and operational requirements. Irrigation, like other farm inputs, has both costs (and risks) and benefits.

A brief description of pressure irrigation systems suited to application in Taranaki region, along with the principal benefits and constraints is presented in Table 7. This is intended to provide a brief overview of the systems rather than in depth description. For all of these systems there are numerous variations, dependent on the manufacturer, equipment selection or design criteria. Table 8 shows the typical range of performance characteristics for these systems, including application rates (that is instantaneous rate which relates to soil infiltration rates and run-off potential), mean application depths per irrigation cycle and return intervals.

The systems fit into three broad categories based on equipment and operation. These are:

- K-lines and long lateral: low-medium pressure impact sprinklers mounted on movable laterals. The key features of these systems are: layout is easily adapted to existing farm layouts and topography (so require few changes to farm infrastructure), lateral are moved daily or twice daily and low application rates, particularly k-lines with less than 3 mm/hr, which reduces potential run-off losses. The systems have proven popular with dairy farmers in Taranaki and other regions due to low capital costs and ease of adaptation to existing farm layouts.
- Centre pivot: horizontal boom rotating around a centre point, with low-pressure sprinkler or spray nozzle mounted along the boom. Centre pivots have been adopted by dairyfarmers in other regions, particularly Canterbury, principally due to benefits of low application rates, short return intervals, low labour requirements and higher pasture production than alternative systems. Constraints include high capital cost and need for and cost of changes to farm infrastructure, such as fences and lanes to optimise system operation.

Table 7: Description, benefits and constraints of irrigation systems

System & Description	Benefits	Constraints
K-lines Impact sprinklers with 15 to 20 m wetted diameter mounted within a pod connected to a low density polyethylene lateral pipe. The lateral is moved by towing (with the pods sledging) to a new position. Typically each lateral comprises up to 10 sprinklers with a total irrigated area of about 0.15 ha per shift	• Low operating pressure • Low capital cost • Low application rates • Suited to existing farm layout and topography	• High labour requirements • High maintenance • Return intervals of 10-15 days
Long lateral: A single impact sprinkler of approximately 30–50 m wetted diameter mounted on a stand and sledge and connect to a low density polyethylene lateral. The sprinkler and lateral are towed to a new position. The irrigated area is typically 0.3-0.5 ha per shift.	• Medium pressure • Low capital cost • Suited to existing farm layout and topography	• High labour requirements • High maintenance • Lower system depreciation • Return intervals of 6-10 days
Centre Pivot: An irrigation boom of up to 700 metres or more in length rotating around a centre point. The boom (referred to as 'spans') is supported on wheeled towers driven by electric or hydraulic motors. Sprinklers are mounted on 'droppers' from the boom. The irrigated area is circular, and dependent on the boom length typically ranges from 30 to 70 ha. On dairy farms the tower wheels ride across lanes and two strand electric fences.	• Low pressure • Low labour requirements • Versatility of application rates and return intervals • Higher pasture production	• High capital cost • Restricted by farm layout and topography • Large irrigated area • Corners not easily watered
Rotary boom irrigator: A rotating boom is mounted on a travelling tower, which is propelled along the irrigation run. Nozzles and/or sprinklers are mounted along the boom. The irrigated strip is up to 600m length and 100 m wide.	• Medium pressure • Large irrigated area (4-6 ha) • Simple operation • Can vary application depths	• Not suited to irregular layout • Some affect by wind • Difficulty of moving in tight areas
Fixed boom irrigator: Sprinklers and/or spray nozzles are mounted on fixed boom (non-rotating). The boom is mounted on a travelling tower, which is self propelled. Typically irrigation runs are up to 600 m and 100 m, with an irrigated area of 5 – 6 ha per run.	• Medium pressure • Large irrigated area • Simple operation • Variable application depths	• Not suited to irregular layout • Poor performance in wind • Moving difficulties in tight areas
Gun irrigator: Large nozzle spray gun mounted on hose (with or without reel), usually self-propelled. Typical systems comprise of a hard-hose and reel which retracts the gun, which is mounted on a wheeled or sledged trolley.	• Medium capital cost • Versatility of applications • Low labour (hard hose types) • Easy to shift (hard hose types)	• Poor performance in wind • High operating pressures • High instantaneous rates leading to runoff

- Travelling irrigators: a variety of travelling irrigator types exist, including rotary boom, fixed boom, and spray guns with differing combination of hard and soft hoses. These systems are best suited to flat to undulating topography and where farm and paddock layout enables irrigator runs of more 300 to 600 metres. System performance and uniformity is affected by high winds. Low pressure fixed boom irrigator can have very high application rates (>60mm/hr).

Table 8: Summary of typical system performance and schedules

System	**Application Rate (mm/hr)**	**Application Depth (mm)**	**Return Interval (days)**
Centre pivot	3 – 30	5 - 50	1 - 10
K-lines	2 - 3	50 - 70	12 - 20
Long lateral	8 - 10	30 - 50	6 - 10
Travelling irrigator(1)	15 - 30	20 - 40	7 - 20

Note: (1) Travelling irrigator includes booms (fixed and rotary) and guns

As indicated above (Section 4.1), k-lines and long lateral have proven popular in Taranaki, which is largely a function of suitability of these systems to farm layouts and the relatively low capital cost compared to other options. It may also be related to the irrigation being regarded as a supplementary option to improving farm productivity, needed only in some seasons. These systems require higher labour and maintenance inputs than other options, with the need to move lateral daily and wear and tear associated with towing laterals.

A limited number of centre pivot systems have been installed to date, mostly in near coast locations (with higher soil moisture deficits) and on the lower waterholding soils. The principal attraction of this system is the low labour requirement and versatility of operation, with the system capable of applying low application depths on short return intervals. However, applications in Taranaki are likely to be limited due to the relatively high capital cost for smaller systems therefore need for higher returns, and limitations of suitable farm layout to optimise system operation.

As with centre pivots, a small number of travelling irrigators have been installed in the region. This possibly also reflects the limitation of their suitability for the range of operating conditions, such as paddock layouts and wind (as discussed below).

4.3 Irrigation Efficiency

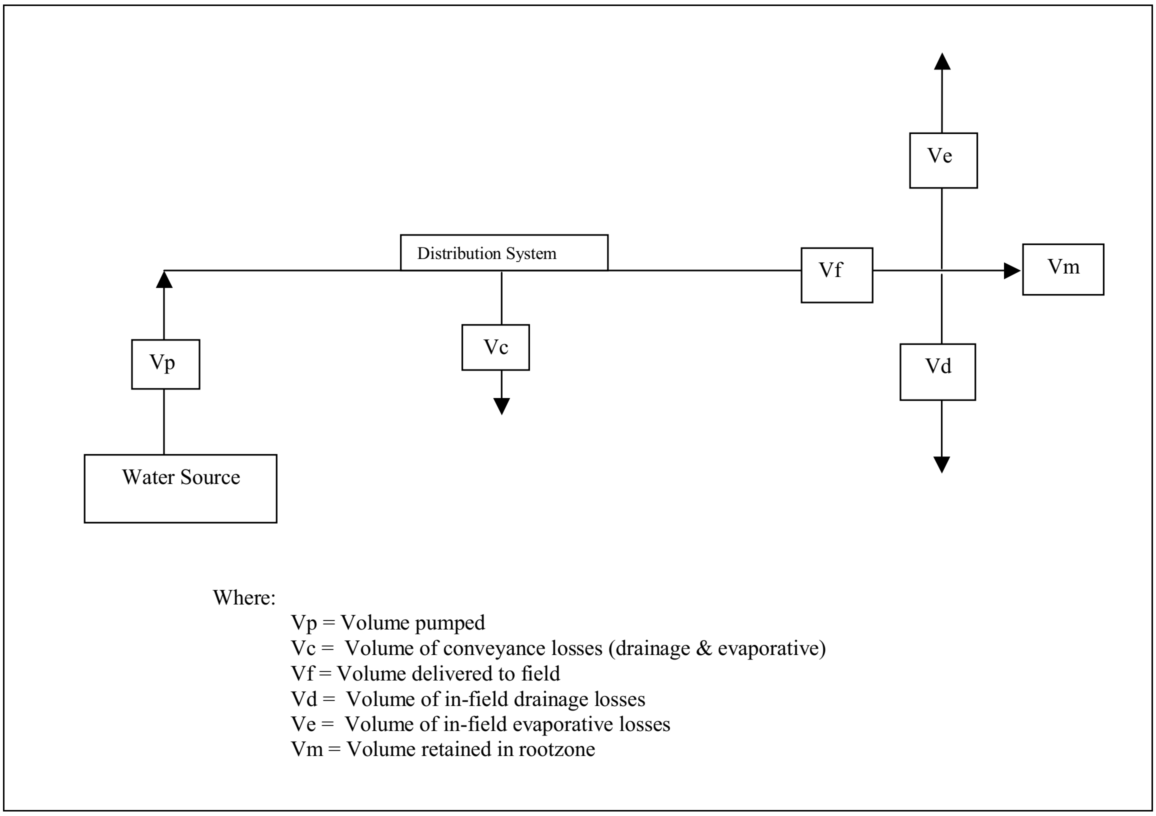
The efficiency of water use is an important and significant component of water allocations. For some systems water losses may contribute more than 30% of the total allocation. Therefore, for the development of water allocation rules, it is important to understand the factors that influence system performance and likely sources of water losses. To meet water demand and encourage efficient use, these rules need to be based on efficiency levels that are attainable under typical field conditions. The following subsections present relevant definitions of efficiency and outline factors that lead to inefficiencies and design and management strategies to improving efficiency.

4.3.1 Definitions of Irrigation Efficiency

There are a number of definitions and indicators of irrigation efficiency, some of which are relevant to irrigation management performance while others more specifically define system performance. The measure of efficiency is time dependent and may range from short time intervals such as single applications to longer periods such as season or annual. At the farm level, efficiency is variable between irrigation events and locations due to the variability of site and operating conditions.

For the purposes of resource allocation, irrigation efficiency is based on the performance for a 'well designed and managed' system. This is in essence the potential system efficiency based on acceptable design criteria and irrigation scheduling to meet crop water demand.

Figure 1 shows the key flow components of an on-farm irrigation system from pump to the rootzone. The units of flow and losses can be expressed either volumetrically (m^3) or as the equivalent depth of irrigation (mm).



Where:
Vp = Volume pumped
Vc = Volume of conveyance losses (drainage & evaporative)
Vf = Volume delivered to field
Vd = Volume of in-field drainage losses
Ve = Volume of in-field evaporative losses
Vm = Volume retained in rootzone

Figure 3: Key Flow Components of On-farm Irrigation (after Bos & Nugteren, 1974)

4.3.2 System Efficiency

The system efficiency is the ratio of pumped volume (Vp) to water stored or retained within the crop root zone (Vm).

$$\textit{System efficiency} \quad = \quad \frac{\underline{\textit{Water stored in the crop root zone (Vm)}}}{\textit{Pumped volume (Vp)}}$$

Losses or inefficiencies within the system include conveyance losses (Vc) and losses within field due to surface evaporation (Ve) and drainage (Vd). For pressure irrigation systems, the majority of losses occur as drainage losses due to variations in application uniformity as discussed below. Generally surface evaporation and conveyance losses are low.

The factors that influence the water stored within the crop root zone (Vm) are; crop rooting depth, soil waterholding capacity and soil water content at the start of irrigation. Rooting depth varies between crop type and growth stages. The crop type for this study is grass for which the assumed rooting depth is 0.5 m. Soil waterholding capacity is a largely a function of soil texture with fine textured soils such as loams holding more water than coarse textured sands. As discussed above, the profile readily available water (Praw) was used for this study. Water content at the start of irrigation is a function of irrigation management. Typically the 50% depletion level is the basis for initiation and return of irrigation.

The factors that influence pumped volume are principally the application depth and application uniformity. Application depth is the depth of application to recharge the soil moisture within the root zone to the upper drainage limit (commonly called field capacity). In principle it should be constant and is a function of soil water holding capacity, rooting depth and a predetermined soil water depletion level (25-50% dependent on crop and soil parameters).

Application uniformity is the uniformity of application within an irrigated area. It is commonly measured as the Christiansen uniformity of coefficient [1](CU), which is a measure of the variability of application from the mean rate. For the design of sprinkler and travelling gun systems CU values of 80% or higher are recommended (Benami, 1983). Sprinklers operating under field conditions typically have CU values closer to 70%.

4.3.3 Application Efficiency

The application efficiency is the ratio of applied to stored water within the crop root zone (Vm) to the total water applied to the soil (Vf). It does not include water losses between the source and application point (Vc). However, for pressure irrigation systems these are generally low.

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[1] Uniformity coefficient = $100\left(1\;4\;\frac{0\,|\times\;4\;\bar{x}|}{0\times}\right)$

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

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

For pressure systems, where conveyance losses (Vc) are minimal, application efficiency is close to or the same as system efficiency. Therefore application efficiency is commonly adopted as the basis of assessment of system performance. For these systems inefficiencies are related to application uniformity and losses due to surface run-off and/or deep drainage.

4.3.4 Other Irrigation Efficiency and Performance Indicators

While application efficiency is the most relevant definition of irrigation efficiency there are also a number of indicators and definitions. Listed below is a summary of some of these.

i) System Capacity

The system capacity is commonly used as a benchmark to assess the ability of an irrigation system to meet evaporative demand. It is expressed as litres per second per irrigated hectare (l/s/ha). The comparison of design and actual system capacity is indicative of the relative capacity of the system.

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

Where actual system capacity is significantly higher than the design capacity, there is potential for over irrigation and reduction in efficiency. Where actual is significantly lower than design capacity, the system will be inadequate to meet peak crop water demand and while irrigation efficiency may be high, it may result in suppression of crop yields, thereby reducing water use efficiency.

System capacity for comparative purposes is based on 24 hours per day. It may also be calculated on hours of system operation per day. For sprinkler and travelling gun systems the actual hours of operation are typically around 20 hours, due to time required for shifting of equipment and downtime for maintenance. For example, a travelling gun irrigator will operate on two 10 hour runs per day, with 1-2 hours required to move the irrigator between runs.

ii) Hydraulic Efficiency

The hydraulic efficiency is an indication of the system hydraulic performance. It gives an indication of how much pressure is lost between the delivery and discharge points.

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

Hydraulic efficiency is a useful indicator for the evaluation of system design. Low efficiency may be due to high friction losses because of poor selection of pipe diameters and configurations and/or selection of a pump duty (pressure) higher than system requirements. It may also, in some cases, be due to large variations in elevation within the system and reflect the additional system pressure required to overcome these variations.

iii) Water Use Efficiency

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.

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

While it is beyond the scope of this study to include water use efficiency evaluations, these may be a consideration in the future development of water allocation policies.

iv) Energy Efficiency

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.

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

Like water use efficiency, detailed analysis of energy efficiency is beyond the scope of this study. However, it would be a useful component in any future study(s) investigating economic costs and benefits of water allocation policy.

4.4 Factors Affecting System Efficiency

The principal factors influencing application efficiency are system design and management. The key factors are:

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

ii) System Design: The system design parameters represent the potential system efficiency and therefore inefficiencies. Design related factors include:
  - Irrigation rate - selection of outlets or operating pressures with application rates in excess of soil infiltration capacity leads to surface-ponding and run-off.
  - Application uniformity – selection of outlets and/or outlet spacings with low application uniformity increases losses.

Table 9 shows typical water losses (%) from both sources for pressurised irrigation systems in New Zealand. Much of the focus on efficiency 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. 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.

Table 9: Typical Water Losses (McIndoe, 2000)

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%

In the Taranaki, wind is a major factor to take into consideration in system design and operation. Figure 4 shows the mean monthly wind velocity (km/hr) for three locations: New Plymouth, Normanby and Stratford. Wind velocities are relatively high in all three locations, at more than 10 km/hr and in excess of 15 km/hr in New Plymouth.

Wind velocity impacts on the application uniformity of sprinkler and spray irrigation systems by distorting the wetted diameter and pattern. In general, to maintain the application uniformity (CU), spacing between sprinklers or irrigation runs is reduced as wind velocity increases. For impact sprinklers, as a guide it is recommended that at wind velocities between 3 to 6 km/hr the spacing should be reduced by 10% and at velocities of 6 to 12 km/hr by 30 to 35% (Benami, 1983). For gun irrigators, the spacing between irrigation runs is reduced by 20% at winds greater than 12 km/hr.

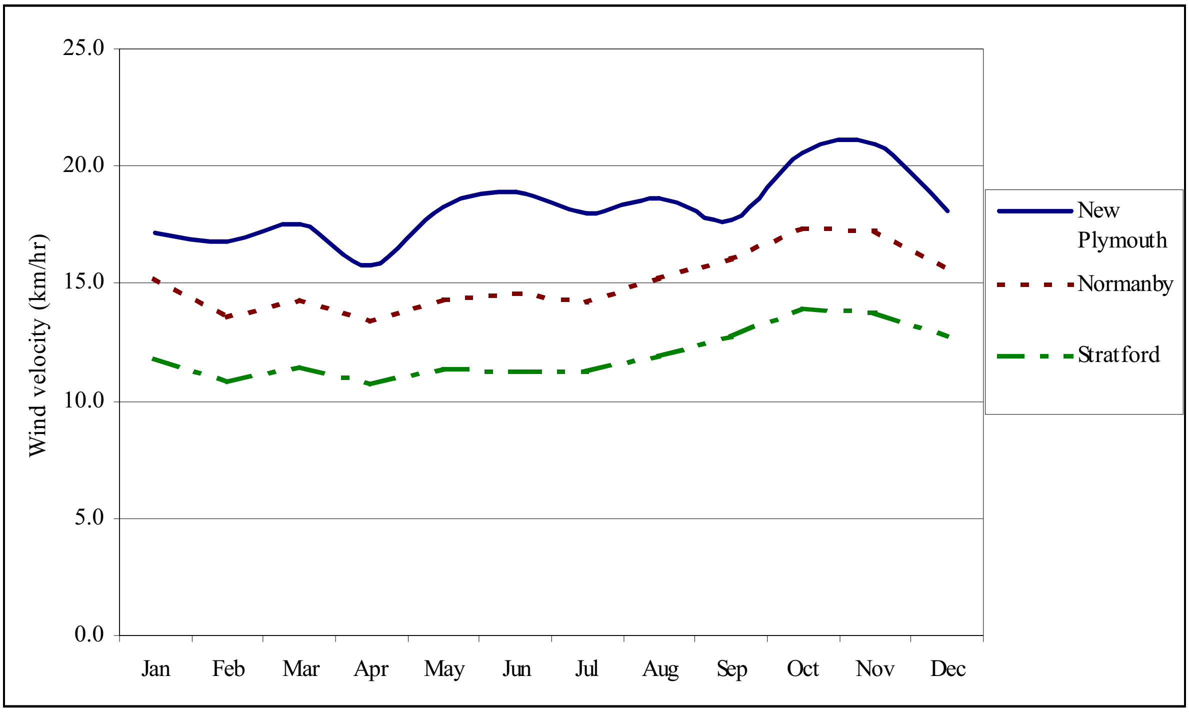

Figure 4: Mean monthly wind velocity for New Plymouth, Normanby and Stratford

Figure 5 indicates the frequency of winds over the irrigation season (Nov-Apr) over an 11 year period (1990-2001) at New Plymouth. The y axis indicated the percentage of time that wind velocity is less than the indicated value (x axis). It shows that wind velocity was less than 12 km/hr for less than 20% of the period. The implications for irrigation design is that sprinkler and irrigator run spacing will need to take into consideration the frequency of high winds and therefore need to be reduced to maintain application uniformity.

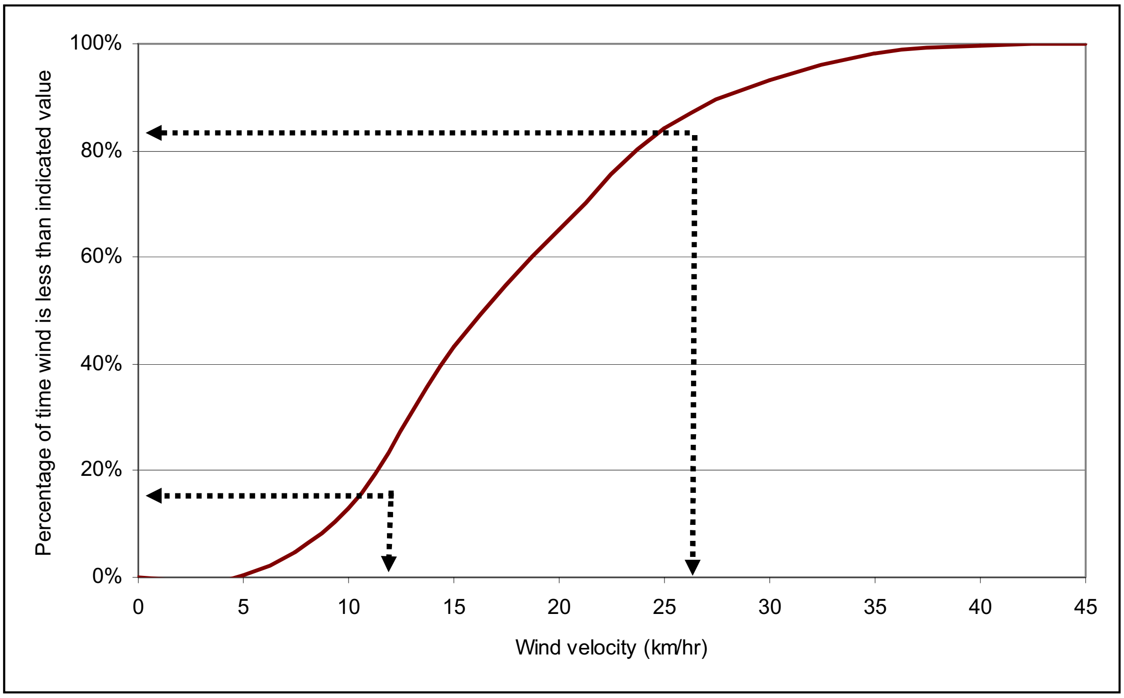

Figure 5: Frequency of winds at New Plymouth (Nov-Apr) over period 1990-2001

There is little published information on the impact of high winds on irrigation system performance. However, it is likely to adversely affect application uniformity and increase evaporative losses. As indicated in Figure 5, for the New Plymouth site, wind velocities were more than 25 km/hr for approximately 15 % of the time. System operation should be avoided during periods of high wind. On this basis it is suggested that the non-operational period for system design, due to high winds, could be in the order of 15-20% of the time. This should be a factor taken into consideration in system design, with a reduction in the daily hours of operation. For example, a 20 percent reduction in the nominal irrigation day from 20 to 16 hours increases the required pump duty by 20% and therefore take rate (l/s/ha), though the daily volumetric allocation remains unchanged.

4.5 Irrigation System Costs

This section presents a summary of the expected costs of irrigation systems in the Taranaki region. These costs have been derived from limited information available for existing systems in the region and from information on system costs in other regions. The derivation of costs also forms part of the irrigation cost and benefits presented in Section 5.

4.5.1 Capital Cost

There is currently limited information available on irrigation system costs in Taranaki. However, information on system capital costs is expected to be similar to those in other regions as system design and specifications are similar. Table 10 presents a summary of typical and range of capital costs for irrigation systems based on Lincoln Environmental records. These costs are for irrigation components, mainline, hydrants, and irrigator or lateral and sprinklers. It excludes the cost of pumps, power and other associated infrastructure, the cost of which is dependent on water source (surface or groundwater), location and system duty. As a guideline these costs are estimated to range between $500 to $1,000/ha dependent on water and extent of farm infrastructure development.

The principal factors, apart from system type, that influence capital costs, include:

- Elevation difference between water source and irrigator: the greater the difference the higher the required pump duty.
- Distance from water source: the greater the distance, the higher the operating head (therefore pump duty and motor rating) and/or larger mainline diameters (therefore higher pipe costs).
- Distance of water source from power source: the greater the distance the higher the cost of power supply infrastructure, transmission lines etc.
- Farm layout: the more irregular the farm shape, the more extensive the mainline network, therefore higher cost.

Table 10: Typical system capital costs (excluding pumps, power etc)

System type	**Irrigator** [(1)]		**Total** [(2)]
	Typical	**Range**	
Rotary boom	1,800	1,700 – 2,000	2,200 – 3,000
Fixed boom	1,900	1,800 – 2,100	2,300 – 3,100
Centre-pivot	1,800	1,300 – 2,300	1,800 – 3,330
K Line	900	800 – 1,000	1,300 – 2,000
Long lateral	1,250	1,100 – 1,500	1,600 – 2,500
Guns	1,800	1,500 – 2,000	2,000 – 3,000

Notes (1) excludes pump and power cost
(2) inclusive of pump and power supply cost

In addition to the above costs there may also be capital costs associated with development of farm infrastructure, such as:

- Lane realignment (particularly for centre pivot and travelling irrigators to enable irrigator operation)
- Re-fencing to optimise irrigator runs
- Levelling of paddock
- Removal of hedgerows to enable efficiency irrigator operation

The scale of these costs is very much, farm and farmer dependent, which may (in total) range from ten to hundreds of dollars per hectare. As an example, associated development costs, including lanes, relocation of troughs, fencing and removal of hedges, for a centre pivot system installed on a farm near Manaia, in 2001 were approximately $ 700 per hectare.

The above capital costs form the basis for the analysis of irrigation costs and benefits presented in Section 6.0.

4.5.2 Operating Cost

The key components of system operating costs are:

- Power consumption is a function of system duty and pumped volume. The higher the system duty, the greater the power requirements per unit volume of water. In Taranaki the majority of water takes are from surface sources, therefore the duty head is the difference in head between the water source and the elevation and operating head at the sprinkler outlet. The cost per unit volume of water is estimated to range between 0.03 to 0.05 $\$/m^3$ for k-lines and travelling gun irrigators respectively (based on a cost of power of $0.12/kWh).

- Labour requirements for system operation, such as moving laterals and irrigators. Labour requirements and therefore costs, vary between systems, from low inputs for centre pivots to high inputs for manual move systems such as k-lines and long laterals.

- System maintenance including repairs, routine maintenance, which vary between systems, dependent on materials, construction and operation. K-lines and long laterals with a high proportion of polyethylene pipe incur relatively high maintenance costs, compared to the more robust and heavily constructed centre pivot.

The irrigation costs and benefits presented in Section 6 are based on a series of assumed values for labour and maintenance costs, related system type and irrigation rate.