5 PRODUCTION RESPONSE – GRAZING MANAGEMENT

Irrigation provides the basis for consistent grass production and therefore changes the dynamics of on-farm feed budgeting and grazing management. The use of irrigation greatly reduces the variability of annual production by reducing the impact of summer and autumn droughts. As a consequence, cow feed requirements and grazing rotations can be more consistently predicted and planned.

This section presents an evaluation of the impact of irrigation on pasture production and consequent impact on feed management. It also discusses the potential effects of changes in grazing management on water demand and soil pugging.

5.1 Pasture availability & utilisation

The primary objective for irrigation is to improve the reliability of pasture production to meet fresh and supplementary feed requirements. During the milking season the best option for optimum milk solids production is to meet cow feed requirements with fresh pasture. Higher levels of milks solid production per cow are generally achieved on pasture than for alternative feed supplements. Optimum summer grass production also enables the production of hay and/or silage to carry over to meet late autumn and winter feed requirements.

Yield response function

The yield response of pasture to irrigation was evaluated for the eight irrigation zones (Section 3) based on the daily soil water balance. Appendix H presents a description of the empirical approach and values adopted for the assessment of response to irrigation. The estimates for yield response are based on upper limits for irrigated pasture of approximately 16,500 and 17,200 kgDM/ha/yr for inland and coastal zones respectively. These are lower than maximum reported production levels, but are reasonably conservative upper production levels typical for an 'average' farm.

As an example of the response to irrigation, Figure 6 shows the predicted monthly production levels for non-irrigated and irrigated pasture within irrigation zone 2 (Normanby). Irrigation increases pasture production during the summer and autumn months from January through to March. In an average year it reduces the impact of summer and autumn droughts producing an additional 500 to 700 kgDM/ha per month over the January to March period.

Table 11 lists a summary of the mean and maximum annual response to irrigation for the irrigation zones. The mean values are the average increase in production in kgDM/ha/yr that could be expected over a 16 to 20 year period, while the maximum values are the highest response recorded over this period. As to be expected from the variations in irrigation demand between zones (Section 3.3), there is considerable variation in pasture production between zones. Pasture response is lowest in the zones with low annual irrigation demand (zones 1 and 8, Stratford and Inglewood), with an increase of less than 800 kgDM/ha/yr (approximately 5% increase). The highest response is predicted for zone 3 (Inaha), with nearly 4,500 kgDM/ha/yr (25% increase).

The above yield response values form the basis for the evaluation of irrigation costs and benefits presented in Section 6.0.

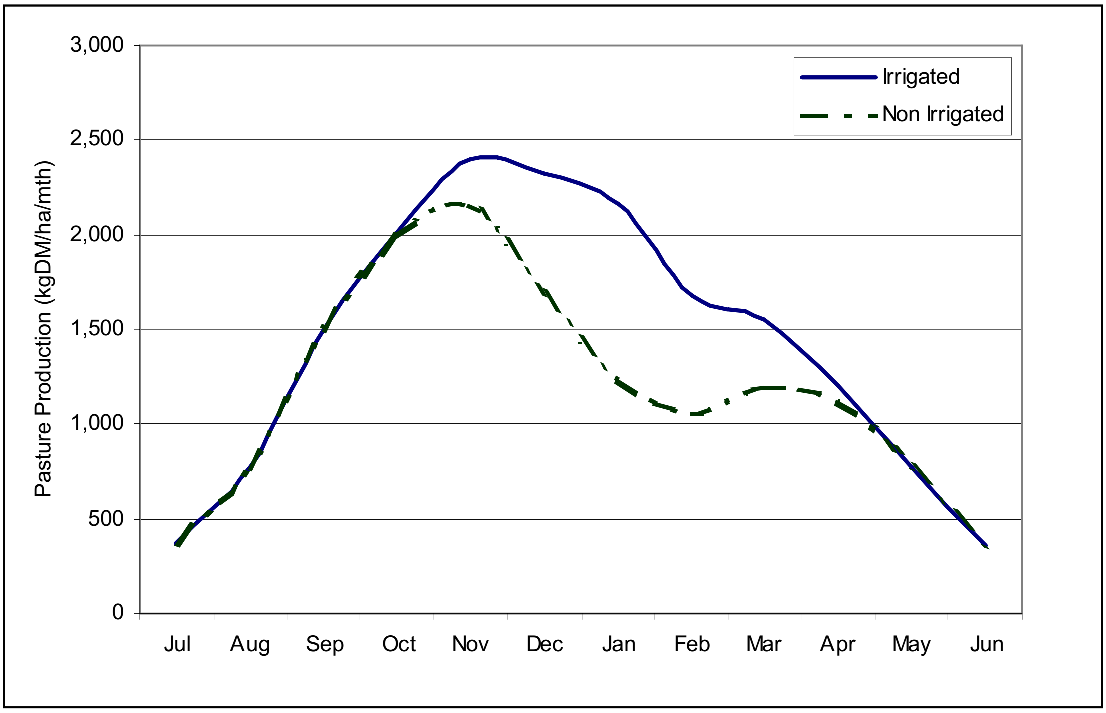

Figure 6: Example of yield response to irrigation – Zone 2 Normanby

Table 11: Yield response within irrigation zones

Zone No.	Zone Name	Yield Response (kgDM/ha/yr)	
		Mean	Maximum
1	Stratford	630	3,140
2	Normanby	2,780	6,280
3	Inaha	4,440	7,750
4	Hawera	3,370	5,450
5	Opunake	2,740	4,850
6	Okato	1,520	4,830
7	New Plymouth	1,770	3,880
8	Inglewood	770	2,360

Utilisation of Pasture

Additional pasture production as a result of irrigation changes the overall feed and grazing management. The typical response to summer and autumn droughts is to lengthen the grazing rotation from approximately 20 days up to 30 to 40 days, dependent on the severity of the feed shortage and to meet shortfalls in cow feed requirements with supplementary feeds. During periods of prolonged shortage, cows are dried-off early to reduce total feed demand.

As shown above, the use of irrigation maintains pasture production over drought periods, therefore pasture production is maintained at or close to maximum levels. Consequently, grazing rotations can be maintained at 20 days without the need for supplementary feeds.

The utilisation of additional pasture production is likely include the following:

- Increase in stocking rate to utilise additional production during the summer and autumn for increased milk solids production per hectare. Typically this would mean an increase in stocking rate by approximately 0.4 to 0.6 cows per hectare
- Reduction in supplementary feeding, such as silage and maize silage during the late summer and autumn
- Fewer cows are likely to dry off early due to higher pasture production in autumn.
- Cows will dry off with a higher condition score
- Conservation of additional pasture production for winter supplementary feeding
- Increase in milk solids production per cow

Salt Washing

Pasture in the south Taranaki area periodically suffers from salt burn, resulting from on shore salt-laden winds. It is reported by farmers in the area that salt-burn occurs most frequently with high winds from the southeast to south. The effects can be extensive, covering a large area as far inland as Eltham. Irrigators in the area reported that the ability to flush salt from pasture as one of the benefits of irrigation. However, not enough is currently known about the frequency of such events or the impact on pasture production to quantify the potential benefits in the financial analysis.

5.2 Pugging Potential

The potential for soil pugging under irrigation is a function of soil type, application depth, application uniformity and stocking rates. Pugging risk is primarily a result of high soil water levels coinciding with intensive stocking rates. Soils with poor drainage qualities and high waterholding capacity are at greater risk of pugging.

While many of the soils within the study area have medium to high waterholding capacity, they generally have good drainage characteristics. Pugging under irrigation is likely to occur where high application depths, as a result of over-irrigation and/or poor application, coincide with grazing. Over irrigation, that is, application depths greater than soil water deficits, is likely to occur when irrigation is scheduled too early or application depths are not matched to predetermined deficit levels. In some situations it may also occur when irrigation precedes high rainfall events.

Poor application uniformity results in localised areas of high application depths, which are more prone to pugging. Higher than acceptable levels of uniformity can be due to a number of factors including: operating system outside design duty e.g. operating too many sprinklers simultaneously, operating under high wind conditions and poor system maintenance resulting in poor sprinkler performance.

In summary, under ‘normal’ irrigation management, where application depth is matched to soil water conditions and application uniformity is acceptable (CU of 70% or greater), the risk for pugging is likely to be low in the region.

5.3 Effect of Grazing on ET

Crop evapotranspiration is a function of potential evapotranspiration and specific crop coefficient (Kc). As indicated in Section 3.1, the Kc value adopted in this study for the water balance model was 1.0. This value is appropriate for a full cover grass crop under rotational grazing with crop height ranging between 0.15 to 0.3 m (FAO, 2000).

The principal effect of grazing on crop evapotranspiration relates to changes in crop height pre and post grazing. On a twenty day grazing rotation, the crop height is typically 30 cm at the start of grazing and reduced to approximately 10 cm. All factors being equal (relative humidity and wind speed), the relationship between crop height and Kc is defined by the following equation.

$$Kc = \left(\frac{h}{3}\right)^{0.3} \qquad (1)$$

For a change of crop height from 30 to 10 cm, Kc decreases by 20%, that is a variation of $^{+}$/- 10% for an average Kc value of 1.0. (Kc range from 0.9 to 1.1.). The rate of grass growth over the 20 day rotation is assumed to be close to linear and therefore the assumed Kc value of 1.0 represents a reasonable average.

The impact of changes in ET due to variations in crop height are likely to be relatively minor due to accumulative effects on soil water levels (that is effects over the return intervals (6 to 14 days (Section 3))).

6 IRRIGATION COSTS AND BENEFITS

The purpose of this section is to evaluate the financial costs and benefits of irrigation within the eight irrigation zones. This provides an indication of the financial incentive for the adoption of irrigation and is therefore an indicator of the potential for development and possible increase in demand for water resources.

6.1 Outline of Method

The approach to evaluating the financial costs and benefits is based on the analysis of the marginal costs and returns to irrigation. The foundation of this analysis is based on the system costs and pasture production benefits presented in Sections 4 and 5 respectively.

Key inputs to the analysis include:

- Irrigation system capital and operating costs
- Cow productivity expressed as kilograms of milk solid (kgMS)
- Pasture production response to irrigation (kgDM/ha)
- Returns per unit of milk solids ($/kgMS)
- Farm production costs expressed as cost per cow ($/cow)
- Supplementary feed costs as a pasture substitute ($/kgDM/ha)

The analysis is based on the following parameters and rationale:

- Per cow production level of 330 kgMS/yr
- Initial stocking rate of 3.2 cows per hectare for all zones
- Per cow annual intake rate is 4,600 kgDM of which approximately 3,900 kgDM is consumed during the milking season
- Pasture production increases (due to irrigation); 50% contributes to increased milk solids production (as a result of increased stocking rates) and 50% contributes to conservation of supplementary feeds (with a reduction in use of off-farm supplements)
- Milk solids returns at $4/kgMS
- The base case is based on the least capital cost irrigation system (k-lines).
- Sensitivity was tested for variations in milk solids returns at 3.5, 4.5 and 5 $/kgMS

Appendix J presents further information and details of the criteria and parameters adopted in the analysis.

6.2 Irrigation benefits

The analysis of the costs and benefits shows that the irrigation marginal benefits are positive for four zones (zones 2, 3, 4 and 5), as indicated in Table 12. The marginal benefits are highest in zone 3 (Inaha) at $236/ha, the zone of highest water demand. There are negative benefits for the three inland zones (Stratford, Okato, and Inglewood) as well as New Plymouth.

The results show that there is good financial incentive for irrigation development in the two southern coastal zones (Inaha and Hawera), as well as Normanby. The potential benefits in Opunake are lower, though still positive.

Table 12: Summary of irrigation marginal benefitss

Zone no.	Zone name	$/ha
1	Stratford	-205
2	Normanby	92
3	Inaha	236
4	Hawera	132
5	Opunake	38
6	Okato	-92
7	New Plymouth	-76
8	Inglewood	-204

Appendix K presents details the analysis of costs and returns for the eight zones.

6.3 Returns to water

An interesting and useful analysis is the cost and returns to water. Table 13 shows the irrigation costs per unit volume, that is the annualised irrigation costs over mean pumped volume and marginal returns per unit volume for the eight zones. Irrigation cost per unit volume varies between the zones, principally due to differences in annual pumped volume. In zones with low mean annual demand (Stratford, Inglewood and Okato) it is relatively high at 17 to 18 cents per cubic metre (m^3). In the zones of relatively high water demand (Normanby, Inaha and Hawera), unit costs are 10 to 13 cents per cubic metre.

The marginal returns are negative in zones with no mean irrigation benefits (Stratford, Okato, New Plymouth and Inglewood). For the zones with a positive irrigation benefit (Normanby, Inaha, Inglewood and Opunake), returns to water range from 1 to 5 cents per cubic metre. These values are relatively low compared to other drier regions, but are to be expected, given the supplementary nature of irrigation in Taranaki.

Table 13: Water per unit cost and returns ($/m³)

Zone no.	Zone name	Irrigation cost ($/m³)	Returns to water ($/m³)
1	Stratford	0.21	-0.14
2	Normanby	0.13	0.03
3	Inaha	0.10	0.05
4	Hawera	0.11	0.04
5	Opunake	0.12	0.01
6	Okato	0.18	-0.05
7	New Plymouth	0.13	-0.03
8	Inglewood	0.17	-0.10

6.4 Sensitivity to milk solids returns

As indicated by events over the past two seasons, the returns (commonly referred to as payout) for milk solid (MS) can significantly vary (by more than 20%) between seasons. Changes in returns may influence the current or future financial feasibility of investment in irrigation. The sensitivity of irrigation marginal benefits was tested for a range of returns above and below the base case ($4/kgMS).

Table 14 lists the irrigation benefits ($/ha) for a range of returns for milk solids from 3 to 5.5 $/kgMS. It shows that for the three inland zones with low response to irrigation (wetter zones) (Stratford, Inglewood, and Okato), irrigation benefits are relatively insensitive to changes in MS return, that is, irrigation is not financially beneficial, irrespective of changes in MS returns. As to be expected in the drier zones (Normanby, Inaha and Hawera) there is a relatively large increase in marginal benefits as MS returns increase. It indicates that if returns increase to 2000-02 levels (close to $5/kgMS) there is likely to be renewed interest in irrigation development.

Table 14: Sensitivity of irrigation benefits($/ha) to milk solid returns

Zone No.	Zone Name	Milk solid returns ($/kgMS)					
		3.0	3.5	4.0	4.5	5.0	5.5
Zone 1	Stratford	-232	-218	-205	-191	-178	-165
Zone 2	Normanby	-38	27	92	156	221	285
Zone 3	Inaha	44	140	236	332	428	524
Zone 4	Hawera	-24	54	132	210	288	365
Zone 5	Opunake	-88	-25	38	101	164	227
Zone 6	Okato	-161	-127	-92	-58	-24	10
Zone 7	New Plymouth	-152	-114	-76	-38	0	38
Zone 8	Inglewood	-237	-221	-204	-187	-171	-154

7 DEVELOPMENT ZONES

The preceding modelling and financial analysis forms the basis for the identification of those areas or zones within Taranaki where irrigation development is most likely to occur in the future. The primary assumption in this identification is that interest in irrigation development is driven by rational financial planning, that is, farmers are most likely to invest in irrigation where there is a positive financial benefit in the medium to long term.

Irrigation is one of a number of input options to increase productivity and returns. Other options include use of supplementary feeds, produced on or off-farm, such as hay, silage, greenfeed maize and dietary supplements such as Proliq. However, unlike other options, irrigation has a large up-front capital cost in plant, which requires debt servicing and maintenance. Current irrigators in the region indicated that they have done their homework in deciding to invest in irrigation and evaluated the potential costs and benefits relative to other options. It is fair to assume that other farmers in the area will do likewise, and to some degree, take guidance from the results of existing irrigators.

Irrigation development potential

The classification of development zones is based on the probability of development within the eight irrigation zones identified in Section 3.0. This classification is based on three levels of probability, based on marginal returns and the variability of these returns over a range of returns for milk solids. Investment in irrigation is likely to be higher in areas where the risks are perceived to be lower. Irrigation development potential is classified as:

- High: marginal irrigation returns are positive for MS returns at $ 3/kgMS and greater than $200/ha at more than $4/kgMS.
- Medium: marginal irrigation returns are positive for MS returns greater than $4/kg MS
- Low: marginal returns are negative at MS returns of $4/kgMS.

Table 15 shows the development potential for the eight irrigation zones. On the above classification, Zone 3 (Inaha) has high development, with positive returns even at relatively low MS returns ($3/kgMS). Three zones (2, 4 and 5 (Normanby, Hawera and Opunake) have medium potential, with positive returns at $4/kgMS, but negative if MS returns slip below about $3.5/kgMS.

Four zones have low development potential, zones 1, 6, 7 and 8, Stratford, Okato, New Plymouth and Inglewood, due to the low or negative irrigation benefits at or less than current milk solids return. In two of these zones, Okato and New Plymouth, there may be interest if there is a return to relatively high milk solid returns (in excess of $5/kgMS), at which point irrigation has a positive financial benefit.

Figure 7 shows the location of the irrigation development zones. The high zone is located on the south coast, centred around the townships of Inaha and Manaia. This area is characteristised by relatively low rainfall (approximately 1,000 mm/yr) and relatively low waterholding capacity soils. The area is also subject to ‘salt burn’ during southerly storms, further supporting the advantages of irrigation.

Table 15: Irrigation development potential

Zone No.	Zone Name	Marginal irrigation returns ($/ha)		Development Potential
		$3/kgMS	$4/kgMS	
Zone 1	Stratford	-232	-205	Low
Zone 2	Normanby	-38	92	Medium
Zone 3	Inaha	44	236	High
Zone 4	Hawera	-24	132	Medium
Zone 5	Opunake	-88	38	Medium
Zone 6	Okato	-161	-92	Low
Zone 7	New Plymouth	-152	-76	Low
Zone 8	Inglewood	-237	-204	Low

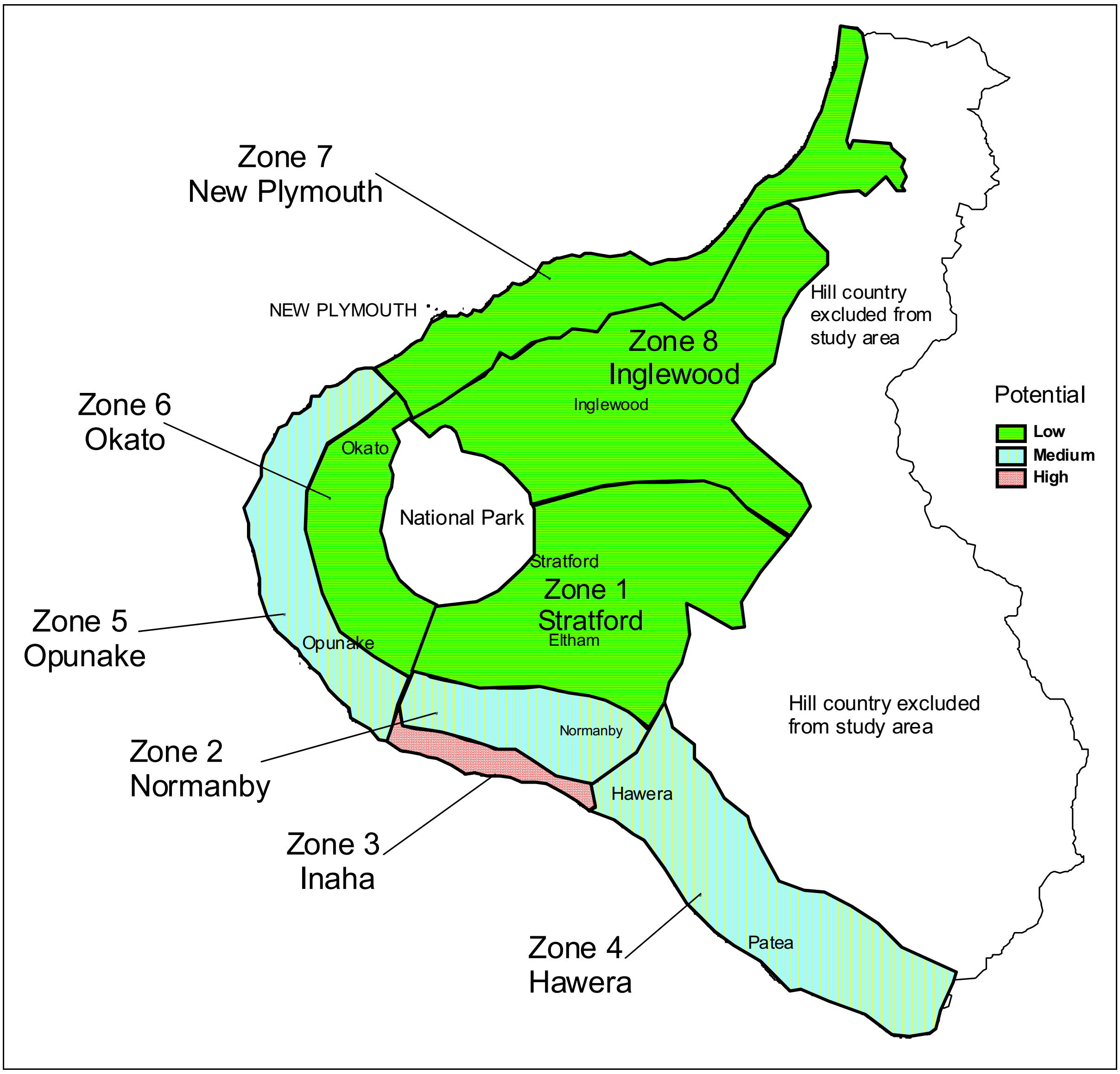

Figure 7: Irrigation development zones

Constraints and limitations of development zones

In identifying these zones, it should be borne in mind that the above analysis is based on a number of assumptions and typical farm values. These include:

- The classification is based on predominate soil type, there is considerable variability of soil types within some zones, particularly zones 4, 5 and 6 (Hawera, Opunake and Okato). Where low waterholding capacity soils occur, such as Castlecliff sands along the coast, irrigation demand and benefits are likely to be higher.
- The derivation of financial benefits is based on analysis of typical cow production levels and farm costs. However there is considerable variability of cow production levels and stocking rates and variations between farms within the zones.
- The financial analysis is based on the 'least cost' option for irrigation, principally K-lines. It is acknowledged that there may variations in irrigation costs for alternative systems and variability between farms dependent on irrigated area, system layout and infrastructure development.
- The study is confined to the evaluation of irrigation demand and associated water allocations. The classification of irrigation zones does not take into consideration the availability of water resources to meet these demands.

Potential Irrigated Areas

As indicated in Section 4, there is currently approximately 2,500 ha of land irrigated in Taranaki, with an accumulative allocated take rate of more than 1,500 l/s. Most of this land is located along the south and west coast, within irrigation zones 2,3,4 and 5 (Normanby, Inaha, Hawera and Opunake).

As indicated in the analysis in Section 6, there could be financial incentives for further development within these zones. Table 16 presents a comparison of potential and actual irrigated areas with high to medium potential. The total potential number and area per zone is based on the NZLRI database, while the potential take (l/s) is calculated from the take rate per hectare per zone (Table 5) and assumes 50% of the total area is irrigable. The table illustrates the difference between current levels of development and potential. It shows that a relatively small proportion of total area has been irrigated to date. It also shows that, if only a small proportion of all dairy farms are irrigated in these zones, demand for irrigation take could increase several fold.

Table 16: Upper limited of irrigated areas and accumulative take rates

Zone No	Zone Name	Dairy Farms – Potential Irrigation			Current Allocations		
		No	Area (ha)	Take l/s	No	Area (ha)	Take l/s
2	Normanby	306	23,692	6,041	3	69	34
3	Inaha	125	9,527	2,762	7	339	381
4	Hawera	240	27,164	9,099	15	1,020	726
5	Opunake	375	34,501	10,867	16	1,049	680
Total		1046	94,884	28,769	41	2,477	1821

The zone of particular interest is zone 3, Inaha, the zone of high irrigation potential, where current allocated take rate is for a total of 381 l/s. However, there is a total of 9,500 ha of dairy farms in the zone which have a combined take requirement in excess of 2,700 l/s, more than nine times the current allocation. While it is unlikely that all of the area would be irrigated, it does highlight the potential demand for water resources in the area should there be a major increase in irrigated area.

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Appendix A: Soil Water Balance Model

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

Inflow = Outflow + Change in Storage

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

Rearranging:

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

Where:

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

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

Available Soil Moisture

For this study the following assumptions and values were adopted:

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

Evapotranspiration

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

$$AET = | (ET_{ref}, PAW_{fac}, Kc) \qquad \text{(A-2)}$$

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

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

$$PET = ET_{ref} * Kc \qquad (A-3)$$

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

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

Drainage

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

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

Rainfall

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

Irrigation

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

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

For this study the rule option adopted was irrigation at a specified depth (approximately 50% of Praw) and specified return period. The return period was established by trial and error, until a solution that met the required probabilistic frequency of soil moisture levels was attained.

The model takes account of the non-uniformity of irrigation applications. It uses the Christiansen's Uniformity Coefficient as the measure of application uniformity. The CU along with the application depth, determines how much of the applied water is actually retained in the crop root zone, and losses to drainage. For this study a CU of 70% was adopted, this is a typical value for well managed sprinkler systems.

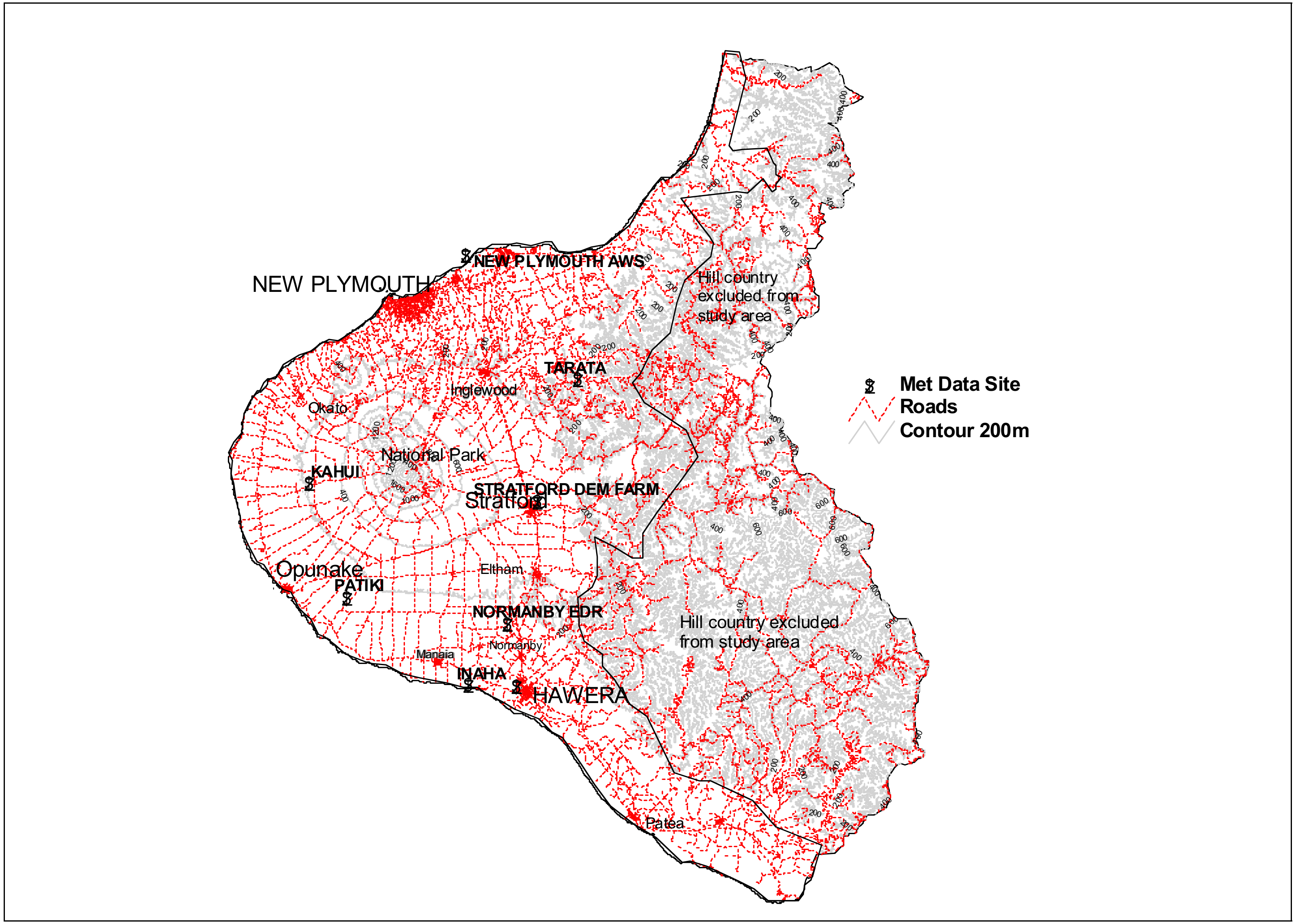
Model Outputs

The model outputs are:

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

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

Appendix B: Met Station Locations



Appendix C: Summary of Rainfall

The table below lists a summary of mean monthly and annual rainfall for locations used in the water balance model.

Table C-1

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tarata													
	137	95	124	152	147	162	159	154	144	170	140	140	1,695
Stratford													
	133	106	148	164	169	181	202	191	164	227	161	167	2,012
Riverlea													
	97	85	103	120	128	155	168	143	131	153	136	119	1,538
Patiki													
	98	88	96	108	105	134	133	111	103	130	117	108	1,332
Normanby													
	72	70	85	93	90	112	122	103	86	99	92	85	1,109
New Plymouth													
	72	56	65	98	89	101	104	89	90	95	90	93	1,042
Kahu													
	121	103	142	141	160	189	194	173	167	216	160	149	1,912
Inaha													
	73	66	80	84	85	107	103	89	78	90	94	74	1,025
Hawera													
	84	72	87	96	95	122	118	99	91	110	105	88	1,168

Appendix D: Summary of Potential Evapotranspiration

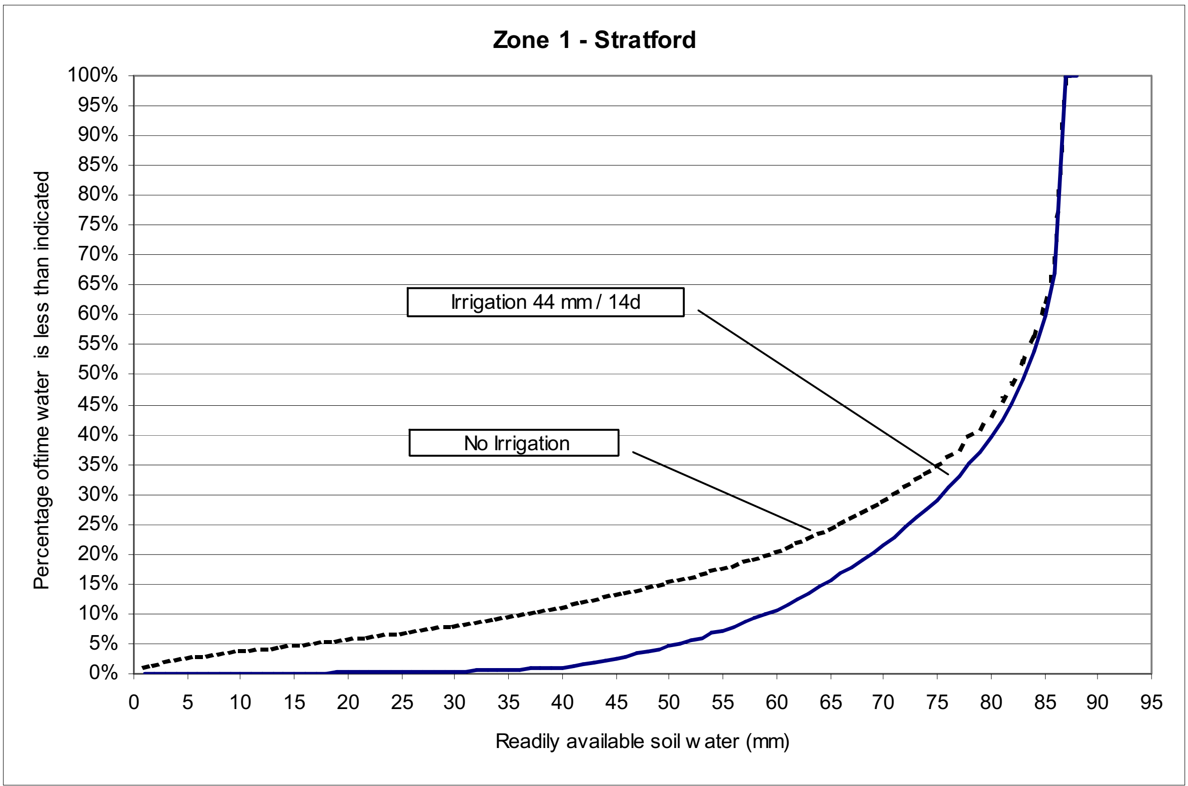
The table below presents a summary of mean monthly and annual PET for the locations and zones adopted in the water balance model.

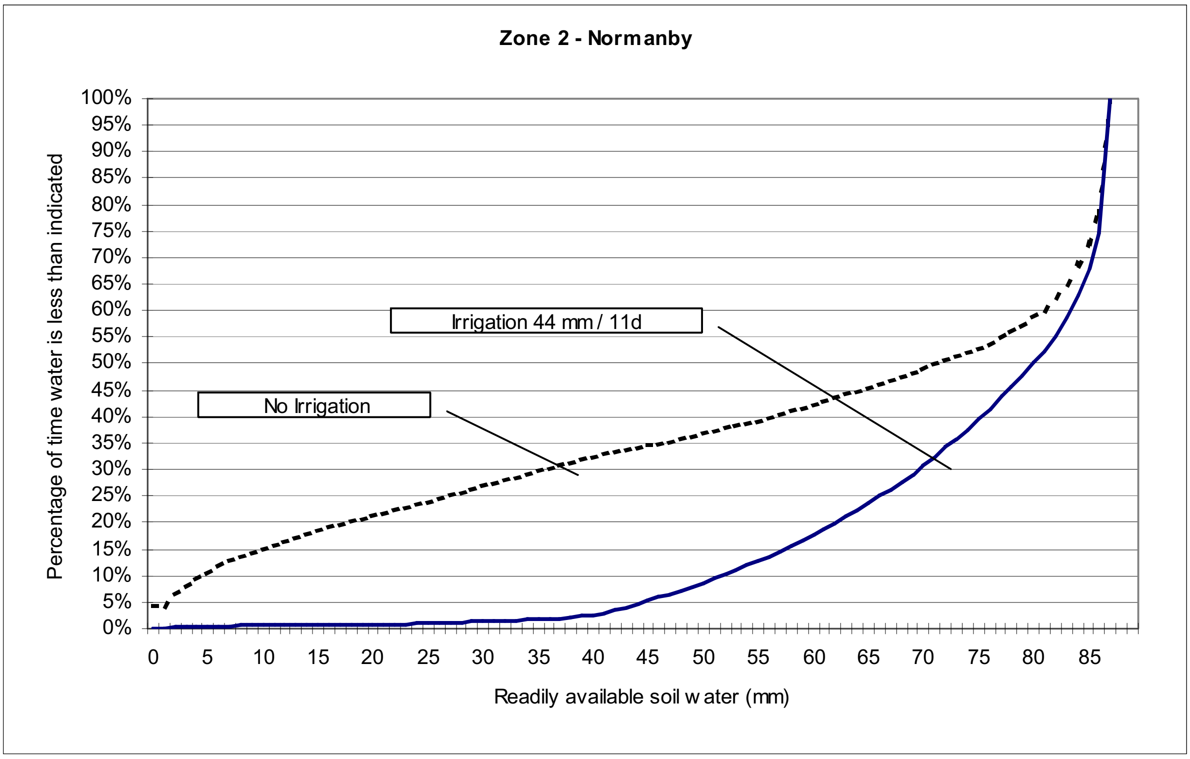
Table D-1:

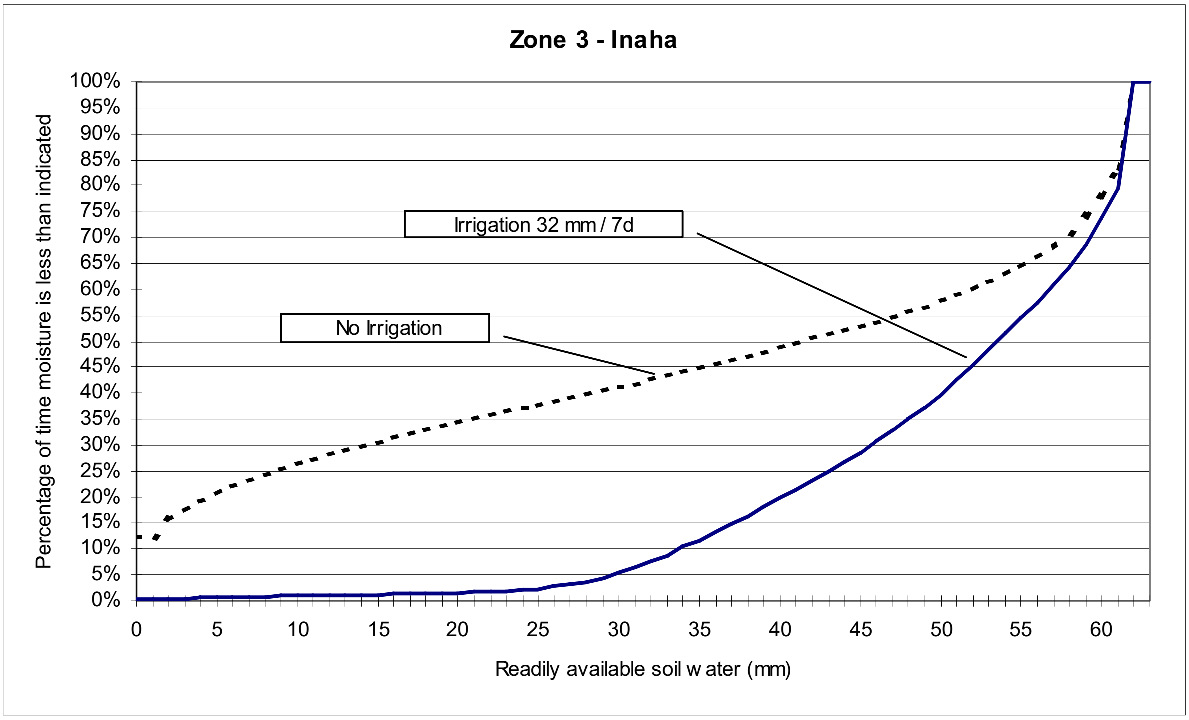
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Stratford													
Mean	116	99	75	42	25	15	18	30	47	74	93	110	745
Std Dev	7	6	8	6	4	3	3	3	4	6	6	8	33
Min	100	87	58	27	16	9	10	23	40	57	84	98	664
Max	127	109	86	51	33	21	22	35	55	82	106	131	803
Normanby													
Mean	129	106	84	50	32	21	23	36	54	81	102	123	818
Std Dev	8	8	6	6	4	4	3	4	4	5	5	13	109
Min	111	92	73	40	24	13	17	29	44	73	93	96	436
Max	143	118	94	61	40	26	30	42	60	90	109	144	886
Coastal (Inaha, Hawera and Opunake)													
Mean	142	116	92	55	35	23	26	40	60	90	113	136	928
Std Dev	9	9	6	6	4	4	4	5	5	6	5	14	120
Min	122	101	80	44	26	15	18	32	48	80	102	106	480
Max	158	130	103	67	44	29	33	46	66	99	120	158	974
New Plymouth													
Mean	141	119	99	63	42	29	34	47	65	90	114	133	976
Std Dev	12	8	8	6	5	3	4	5	7	6	10	11	37
Min	124	105	87	54	30	23	29	38	50	75	96	114	922
Max	165	133	118	75	52	34	46	61	74	106	133	151	1044
Inglewood													
Mean	120	101	85	53	36	25	29	40	55	76	97	113	830
Std Dev	10	7	7	6	4	2	3	4	6	5	8	9	32
Min	105	89	74	46	26	20	25	32	43	64	81	97	783
Max	140	113	100	63	44	29	39	52	63	90	113	128	887

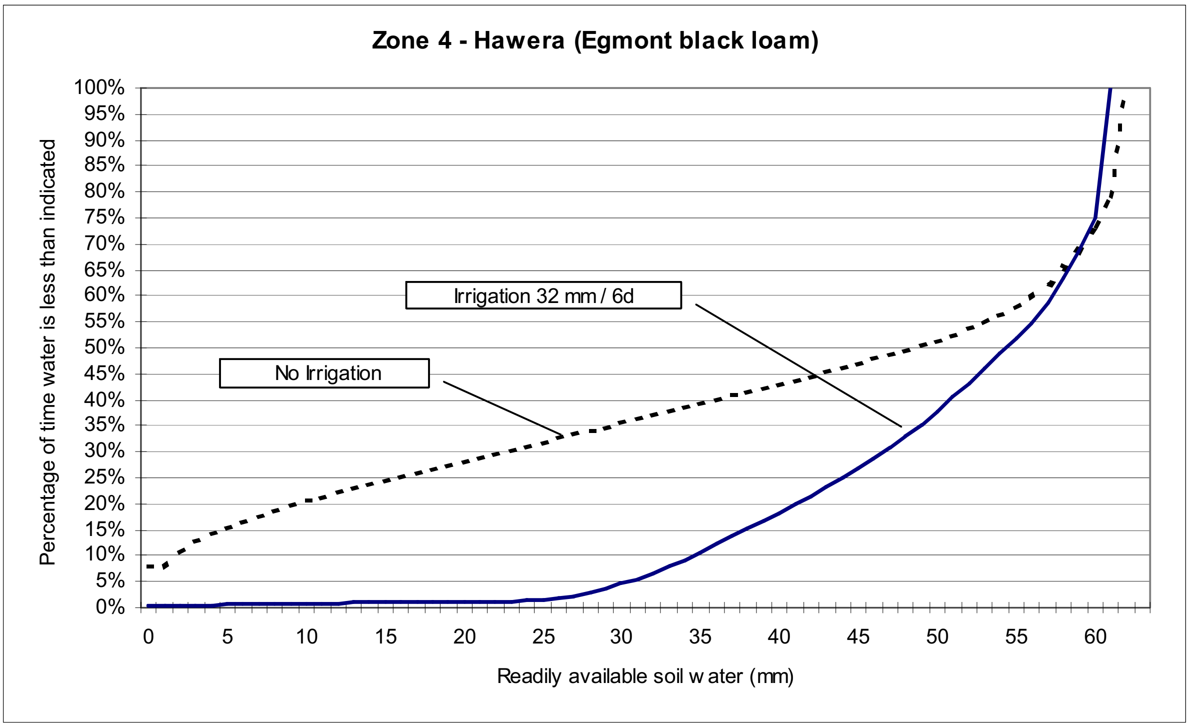
Appendix E: Model Results

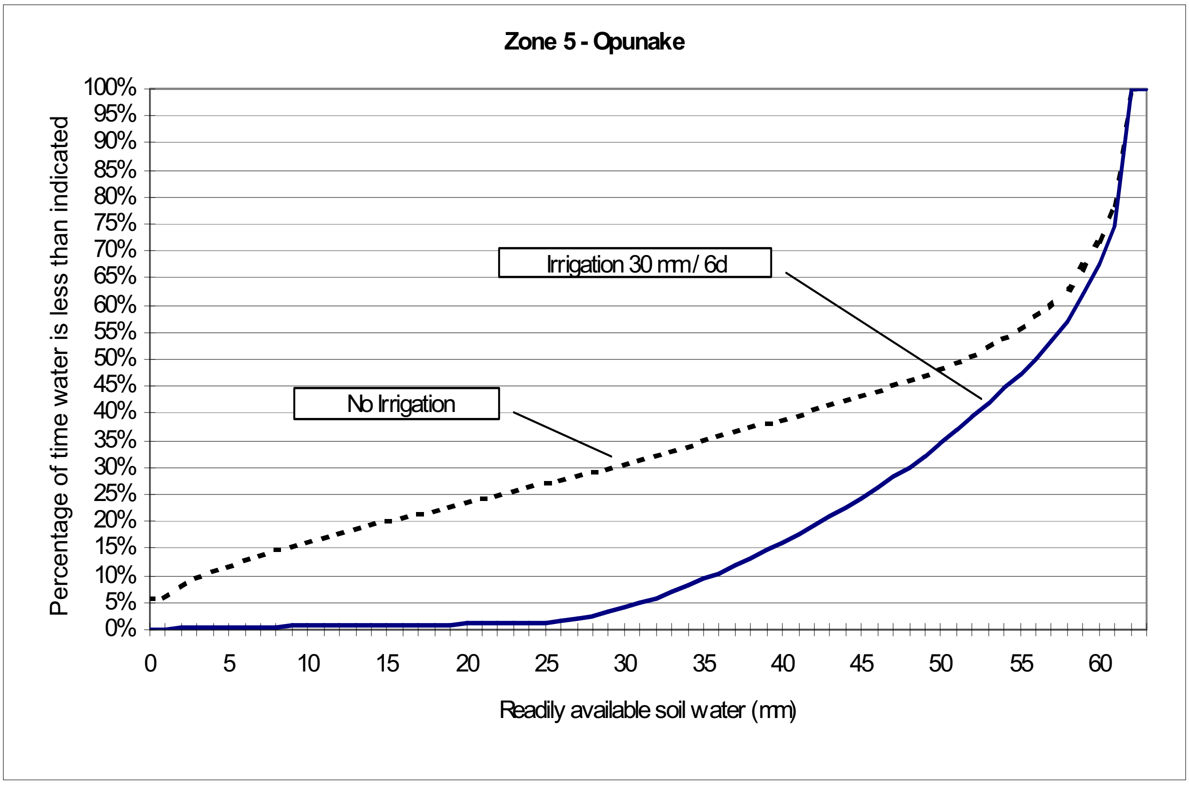
The following series of graphs show the distribution of soil moisture levels for the non irrigation and irrigation scenarios for the irrigation zones

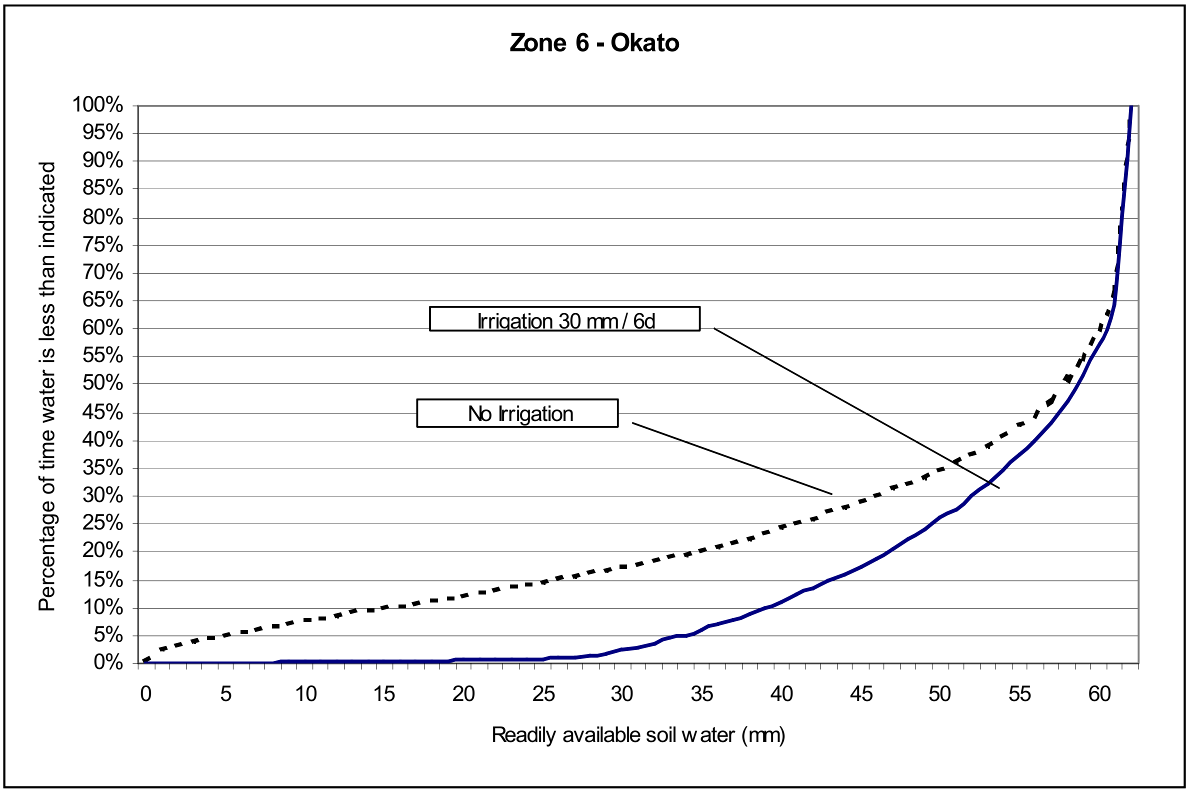


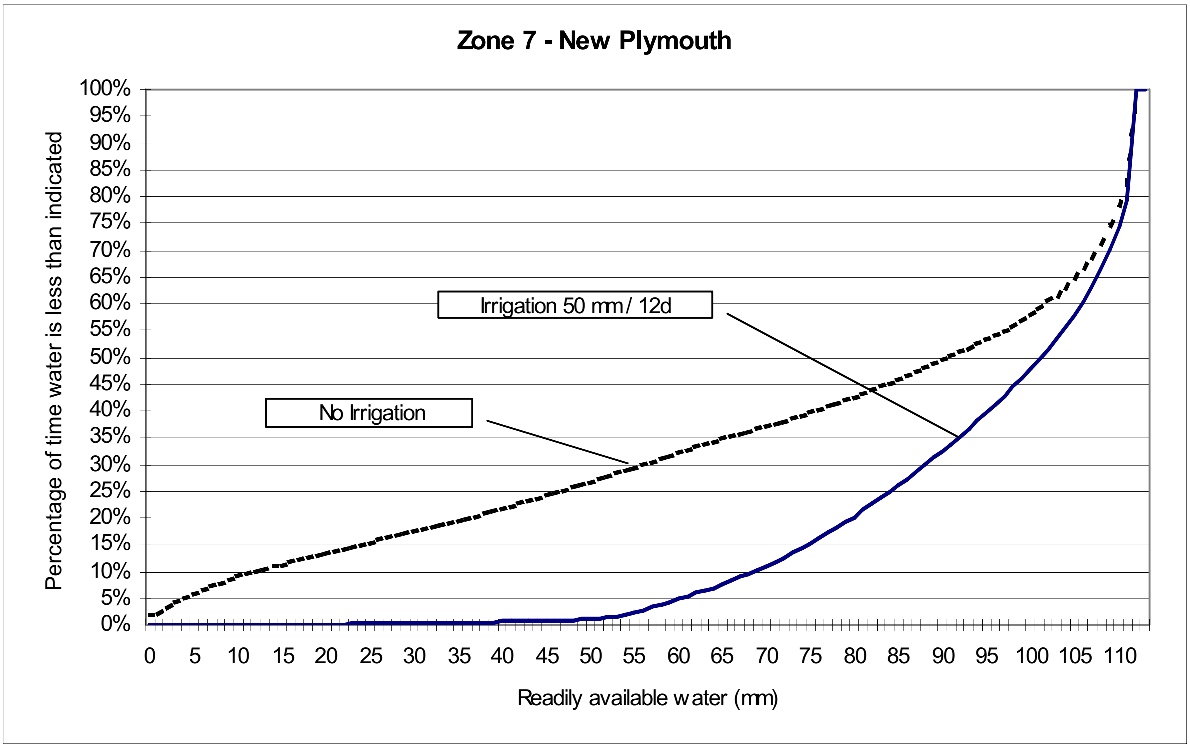


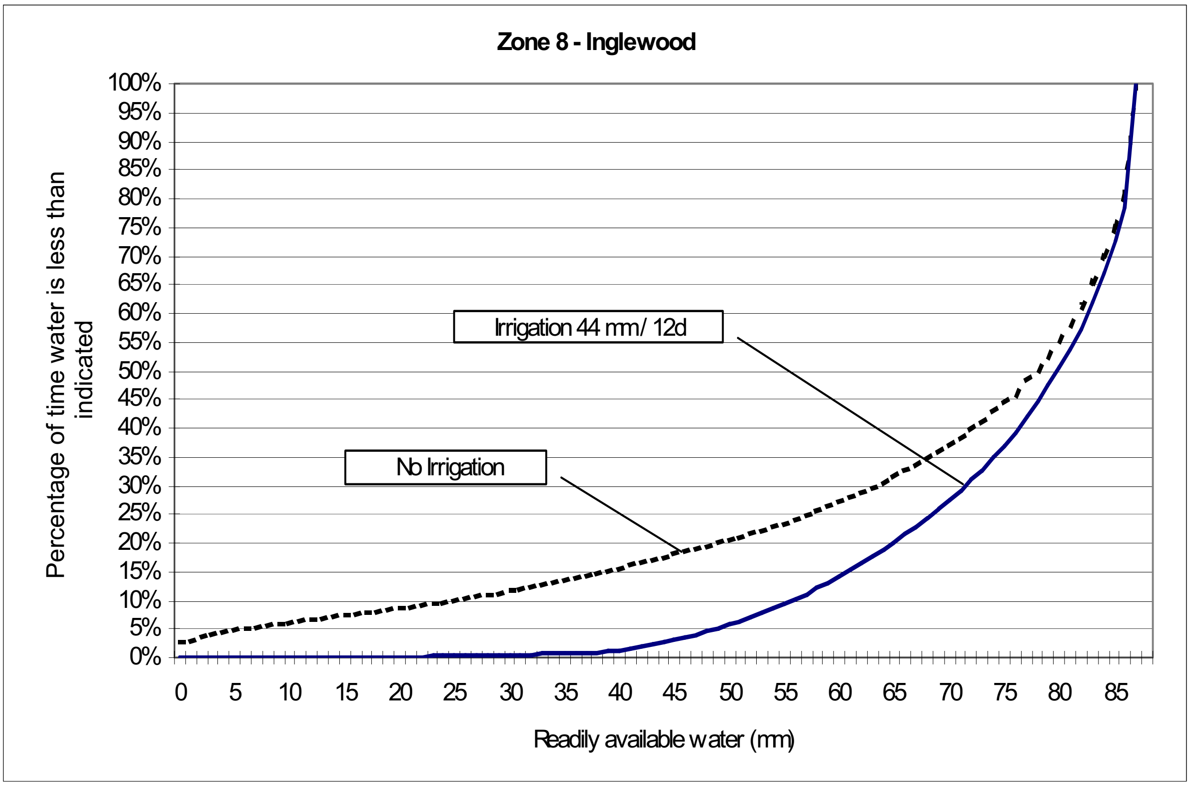

Zone 3 - Inaha
Percentage of time moisture is less than indicated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Irrigation 32 mm / 7d
No Irrigation
0
5
10
15
20
25
30
35
40
45
50
55
60
Readily available soil w ater (mm)


Zone 4 - Hawera (Egmont black loam)
Percentage of time water is less than indicated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Irrigation 32 mm / 6d
No Irrigation
0
5
10
15
20
25
30
35
40
45
50
55
60
Readily available soil w ater (mm)


Zone 5 - Opunake
Percentage of time water is less than indicated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Irrigation 30 mm / 6d
No Irrigation
0
5
10
15
20
25
30
35
40
45
50
55
60
Readily available soil water (mm)


Zone 6 - Okato
Percentage of time water is less than indicated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Irrigation 30 mm / 6d
No Irrigation
0
5
10
15
20
25
30
35
40
45
50
55
60
Readily available soil water (mm)


Zone 7 - New Plymouth
Percentage of time water is less than indicated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Irrigation 50 mm / 12d
No Irrigation
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
Readily available water (mm)


Zone 8 - Inglewood
Percentage of time water is less than indicated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Irrigation 44 mm / 12d
No Irrigation
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Readily available water (mm)

Appendix F: Irrigation Rates (mm)

The table below presents a summary of the mean monthly and annual irrigation depths for the irrigation zones

Table F-1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Stratford (44mm per 14 days (Stratford fine sandy loam))													
Mean	34	46	16	2	0	0	0	0	0	0	12	32	142
Std Dev	27	32	26	9	0	0	0	0	0	0	20	28	62
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	88	88	88	44	0	0	0	0	0	0	44	88	220
Normanby (44m per 11 days (Egmont brown loam))													
Mean	76	65	26	9	3	0	0	0	3	11	41	61	283
Std Dev	20	28	22	18	11	0	0	0	11	25	34	39	117
Min	44	0	0	0	0	0	0	0	0	0	0	0	0
Max	88	88	44	44	44	0	0	0	44	88	132	132	484
Inaha (32mm per 7 days (Egmont black loam))													
Mean	94	79	49	21	4	0	2	2	8	32	54	82	439
Std Dev	26	27	27	23	16	0	8	8	14	26	32	39	79
Min	64	32	0	0	0	0	0	0	0	0	0	0	320
Max	128	128	96	64	64	0	32	32	32	96	96	128	640
Hawera (32 mm per 6 days (Egmont black loam))													
Mean	92	77	47	13	2	0	0	2	4	18	56	74	370
Std Dev	27	26	29	20	8	0	0	8	11	16	36	42	117
Min	64	32	0	0	0	0	0	0	0	0	0	0	0
Max	128	128	96	64	32	0	0	32	32	32	96	128	512
Opunake (30 mm per 6 days (Opua Series))													
Mean	90	66	42	10	2	0	0	2	2	21	45	68	334
Std Dev	23	28	22	15	8	0	0	8	8	18	31	40	103
Min	60	0	0	0	0	0	0	0	0	0	0	0	0
Max	120	120	90	30	30	0	0	30	30	60	90	150	420
Okato (30 mm per 6 days (Awatuna Series))													
Mean	56	52	22	4	2	0	0	0	0	2	24	40	189
Std Dev	27	31	21	11	8	0	0	0	0	8	26	27	86
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	90	120	60	30	30	0	0	0	0	30	90	90	390
New Plymouth (50 mm per 12 days (New Plymouth black loam))													
Mean	55	55	45	7	0	0	0	2	0	7	34	55	259
Std Dev	34	34	31	18	0	0	0	11	0	18	28	34	83
Min	0	0	0	0	0	0	0	0	0	0	0	0	50
Max	100	100	100	50	0	0	0	50	0	50	100	100	400
Inglewood (44 mm per 11 days (Stratford sand))													
Mean	36	52	28	12	2	0	0	2	0	8	18	38	196
Std Dev	32	38	29	24	9	0	0	9	0	17	22	28	103
Min	0	0	0	0	0	0	0	0	0	0	0	0	44
Max	88	132	88	88	44	0	0	44	0	44	44	88	528

Appendix G: Summary of Daily and Peak Allocations

The table below presents a summary of irrigation rate, daily allocation and seasonal peak allocations for the irrigation zones

Table G-1

Zone no.	Zone name	Mean rainfall (mm/yr)	Mean PET (mm/yr)	Application Depth (mm)	Return Interval (d)	Daily Allocation		Take Rate (l/s/ha)	Mean annual (mm/yr)	Annual Allocation (max)	
						(mm/d)	(m3/ha/d)			(mm/yr)	(m3/ha/yr)
1	Stratford	2,012	745	44	14	3.1	31.4	0.40	142	220	2,200
2	Normanby	1,109	843	44	11	4.0	40.0	0.51	302	484	4,840
3	Inaha	1,025	928	32	7	4.6	45.7	0.58	438	640	6,400
4	Hawera	1,168	928	32	6	5.3	53.3	0.67	370	512	5,120
5	Opunake	1,332	928	30	6	5.0	50.0	0.63	356	420	4,200
6	Okato	1,900	843	30	6	5.0	50.0	0.63	189	360	3,600
7	New Plymouth	1,042	976	50	12	4.2	41.7	0.53	259	400	4,000
8	Inglewood	1,600	976	44	12	3.7	36.7	0.46	178	396	3,960

Appendix H: Pasture Yield Response

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

$$Ya = (1-(1-AET/PET) \times Ymax \qquad (H-1)$$

Where:

Ya	is the yield response (potential yield response to irrigation)
AET/PET	is the derived from the water balance model (based on ET reduction factor)
Ymax	is the potential pasture production under irrigation (kgDM/d) (mean monthly value as listed below for the irrigation zones)

Table H-1 lists the Ymax values (kgDM/day) adopted for this study. These values were derived from various sources including published research and local experience.

Table H-1

Zone No	Zone Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Stratford	70	60	50	40	25	8	10	20	50	65	75	75
2	Normanby	70	60	50	40	25	12	12	25	50	65	80	75
3	Inaha	70	60	50	40	25	12	12	25	50	65	80	75
4	Hawera-Patea	70	60	50	40	25	12	12	25	50	65	80	75
5	Opunake	70	60	50	40	25	12	12	25	50	65	80	75
6	Okato	70	60	50	40	25	8	10	20	50	65	80	75
7	New Plymouth	70	60	50	40	25	12	12	25	50	65	80	75
8	Inglewood	70	60	50	40	25	8	10	20	50	65	75	75

Appendix I: Pasture Production Benefits of Irrigation (kgDM)

The table below presents a summary of mean monthly and annual predicted pasture production benefits (kgDM/ha) of irrigation for the irrigation zones.

Table I-1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Zone 1: Stratford													
Mean	168	249	128	36						0	1	53	634
Std Dev	332	421	245	151						1	4	119	694
Min													
Max	1,318	1,680	918	711						3	18	392	3,141
Zone 2: Normanby													
Mean	931	629	357	77						23	248	632	2777
Std Dev	476	351	362	140						80	626	634	1305
Min	58												1056
Max	1580	1234	1189	547						319	2367	1946	6277
Zone 3: Inaha													
Mean	1235	850	504	214						131	543	905	4441
Std Dev	358	347	410	306						473	374	621	1344
Min	480	221	0	0						0	0	0	2356
Max	1724	1382	1544	973						1898	1537	1796	7750
Zone 4: Hawera													
Mean	1027	761	416	137						23	344	777	3365
Std Dev	443	347	387	246						86	360	595	1136
Min	232	227	0	0						0	0	0	1374
Max	1646	1310	1267	773						344	1214	1780	5447
Zone 5: Opunake													
Mean	907	629	303	23						19	313	594	2743
Std Dev	406	400	303	54						66	288	538	1073
Min	22	57	0	0						0	0	0	868
Max	1630	1244	987	180						263	944	1396	4845
Zone 6: Okato													
Mean	481	439	169	43						0	106	296	1,515
Std Dev	427	371	214	135						5	300	456	1,129
Min	0	0	0	0						0	0	0	56
Max	1,138	1,068	665	474						6	1,099	1,593	4,830
Zone 7: New Plymouth													
Mean	521	446	400	97						1	36	260	1768
Std Dev	492	400	365	185						3	92	378	1087
Min	0	0	0	0						0	0	0	2
Max	1226	1219	1225	736						9	358	1224	3879
Zone 8: Inglewood													
Mean	222	214	199	45						0	8	94	768
Std Dev	368	295	298	148						7	35	240	705
Min	0	0	0	0						0	0	0	0
Max	1092	961	930	667						12	133	882	2362

Appendix J: Summary of Financial Model - Assumptions and Parameters

The approach to the evaluation of the analysis of irrigation costs and benefits is based on a simple generic farm model. The model is based on typical stocking rates, production levels and farm expenses for a dairy farm in Taranaki. The evaluation of the irrigation costs and benefits are calculated from a comparison with the non-irrigated base case.

The analysis of costs and benefits of irrigation is based on the following assumptions and parameters:

- Base case farm expenses are derived from typical on-farm expenses (per cow and per hectare) with a pro-rata increase with increase in stocking rate for irrigated farms.

- Stocking rates: the base case is 3.2 cows per hectare, with an increase in stocking rate with increase in dry matter production (as outlined below)

- Cow production: 330 kgMS per hectare per year

- Pasture production benefits: two rules applied:
    - 50% of irrigation pasture production benefits results in an increase in stocking rate at the rate of 4,600 kgDM/yr per cow.
    - 50% of irrigation pasture production benefits are converted to supplementary feed reserves for winter feeding, thereby reducing off-farm supplementary feed requirements and costs

- Irrigation expenses:
    - Annualised capital costs are based on the following criteria:
        - Above ground components (80% of total capital cost) depreciation at 10% per annum.
        - Below ground components (20% of total capital cost) depreciation at 7.5% per annum.
    - Labour costs based on a fixed rate per hectare (system dependent) per number of shifts per season.
    - Operating and maintenance expenses 5% of above ground component capital costs.
    - Power expenses based on system duty, power rate ($/kW) and annual pumped volume.

- Farm expenses:
    - Farm working expenses are based on pro-rata rate per stock units from base case, less cost savings for supplementary feed benefits of irrigation (as outlined above)
    - Non cash adjustments are based on pro-rata rate per stock units from base case.

Appendix K: Results of Financial Analysis

Table K-1

Description	Base Case	Zone 1 Stratford	Zone 2 Normanby	Zone 3 Inaha	Zone 4 Hawera	Zone 5 Opunake	Zone 6 Okato	Zone 7 New Plymouth	Zone 8 Inglewood
Stocking Rate (cow/ha)	3.2	3.3	3.6	3.8	3.7	3.6	3.4	3.4	3.3
MS Production (kgMS/ha)	1,056	1,083	1,185	1,248	1,212	1,182	1,124	1,132	1,089
Income:									
Milk sales	4,224	4,331	4,741	4,991	4,847	4,728	4,497	4,527	4,358
Net Stock Sales	310	318	348	367	356	347	330	333	320
Rebates and Other	26	26	29	30	29	29	27	27	26
Total Income	**4,560**	**4,676**	**5,118**	**5,388**	**5,232**	**5,104**	**4,855**	**4,887**	**4,704**
Farm Working Expenses:									
Wages	243	249	273	287	279	272	259	261	251
Animal Health	173	177	194	204	198	193	184	185	178
Breeding and Herd testing	93	95	104	110	106	104	99	99	96
Farm Dairy Expenses	64	66	72	76	73	72	68	69	66
Electricity	67	69	75	79	77	75	72	72	69
Pasture & Supplements	554	504	332	216	287	341	436	418	493
Fertiliser	467	479	524	552	536	523	497	501	482
Freight	26	26	29	30	29	29	27	27	26
Weed and Pest	32	33	36	38	37	36	34	34	33
Repairs & Maintenance	298	305	334	352	341	333	317	319	307
Vehicle Expenses	163	167	183	193	187	183	174	175	168
Standing Charges	262	269	295	310	301	294	279	281	271
Administration	102	105	115	121	117	115	109	110	106
Other	19	20	22	23	22	21	20	21	20
Total Farm Working Expenses:	**2,563**	**2,565**	**2,587**	**2,591**	**2,593**	**2,590**	**2,576**	**2,572**	**2,566**
Irrigation Expenses									
Annual		171	171	171	171	171	171	171	171
Power		43	85	131	111	100	57	78	59
O & M		72	72	72	72	72	72	72	72
Labour		16	32	68	58	56	32	26	22
Total Irrigation Expenses		**302**	**360**	**443**	**412**	**399**	**331**	**347**	**324**
Total Expenses		2,867	2,947	3,033	3,004	2,989	2,907	2,918	2,890
Cash Surplus		**1,809**	**2,171**	**2,355**	**2,228**	**2,115**	**1,948**	**1,969**	**1,814**
Non cash Adjustments:									
Change in Stock Numbers	202	207	226	238	231	226	215	216	208
Less Run-off Adjustment	54	56	61	64	62	61	58	58	56
Less Labour Adjustment	525	538	589	620	602	587	559	562	541
Less Depreciation	294	302	330	348	338	330	313	316	304
Total Adjustments:	-672	-689	-754	-794	-771	-752	-715	-720	-693
Economic Farm Surplus:	**1325**	**1,120**	**1,416**	**1,561**	**1,457**	**1,363**	**1,232**	**1,249**	**1,121**
Irrigation Marginal Benefits		**-205**	**92**	**236**	**132**	**38**	**-92**	**-76**	**-204**

Note: Irrigation marginal benefit is calculated from a base case farm with economic surplus of $1,325/ha (at stocking rate of 3.2 cows/ha)