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Irrigation REPORT

REDUCING NUTRIENT LOSSES THROUGH IMPROVING IRRIGATION EFFICIENCY

PREPARED FOR
Fertiliser Association of New Zealand

RD18000/1

28/05/2018

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EXECUTIVE SUMMARY

The purpose of this pilot study was to answer three important questions:

- How much can drainage and the associated N-loss to water be reduced by increasing irrigation efficiency?
- What changes in irrigation systems and their management would be needed to achieve this?
- What are the primary incentives and barriers to achieving the changes required?

Existing data from twelve representative dairy farms located in Canterbury were used with well-established computer models to build the technical evidence base needed to answer the first two questions. The third question was addressed using the project team's expert knowledge of irrigation systems and their operating requirements, in conjunction with the technical evidence base.

Changing irrigation practices to make more efficient use of both irrigation water and summer-time rainfall reduced N-loss to water by 27% (~19 kg N/ha/year), on average. The percent reduction ranged from 4% to 58%. These reductions in N-loss to water were achieved without significantly reducing modelled average annual pasture production.

To achieve this degree of N-loss reduction the following changes were made to irrigation management practices:

- The irrigation 'trigger level' (the soil water content at which an irrigation application is initiated) was varied from month to month and in some months is significantly lower than current practice. Most farmers use a trigger level of 50% of the soils water holding capacity throughout the irrigation season.
- The irrigation 'target' soil water content was reduced, compared to current practice, so that after each irrigation event there will still be a soil water deficit. The aim of this 'deficit irrigation' is to always have some capacity to store rainfall that occurs during the irrigation season. This reduces the risk of rainfall-induced drainage and N-loss occurring during the irrigation season.

The irrigation management strategy that achieved the N-loss reductions reported above is as follows:

Month	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Irrigation Trigger (% of soil water holding capacity)	20%	40%	50%	50%	50%	40%	30%	20%
Irrigation Target (% of soil water holding capacity)	80%	80%	80%	80%	80%	80%	80%	80%

To implement this strategy it is essential that:

- Soil water content is routinely measured using reputable soil moisture sensors or soil moisture monitoring service provider.
- The irrigation application system can be adjusted to apply relatively small amounts of water (e.g. 15mm). The depth depends on the soil water holding capacity.
- The irrigation application system has a relatively short return period (e.g. 3 days). This depends on the amount of water applied and the evapotranspiration rate.
- The irrigation water supply is very reliable.

At present about 72% of irrigation application systems in use in Canterbury are very likely to be able to meet the above application depth and return period requirements. An additional 19% may be able to meet these criteria but probably require a comprehensive irrigation design review and some capital

investment in irrigation equipment. The balance almost certainly require replacement of the existing irrigation system.

A recent survey of irrigation management practices indicates that in the area surveyed about 60% of properties have soil moisture sensors installed but that fewer than half of these are actually used to guide day-to-day irrigation decision making.

The main incentives for changing irrigation management practices are economic and regulatory.

Given the low reported actual use of soil moisture monitoring technology as a regular source of data for irrigation management, it appears that the value proposition of improving irrigation management to reduce energy costs is either not sufficiently compelling to justify expenditure of money and management effort on it, or it is not understood.

Regulatory-based incentives to improve irrigation efficiency stem from the implementation of limits on irrigation water use and nutrient discharge. Limits on irrigation water use are typically based on the assumption that irrigation efficiency is 80% or better. Operating at less than 80% efficiency has a high economic cost if irrigation is forced to stop once the seasonal water use limit has been reached. Mandatory reductions in Nitrate loss to water will require changes in land and water management. The results above indicate that changes in irrigation management can, in many cases, contribute significantly to meeting the mandated reductions. The results suggest that N-loss reduction may provide a stronger value proposition for improving irrigation management than does reducing energy costs.

Capital investment is likely to be required on a significant number of farms in order to reduce N loss through using irrigation water and rainfall more efficiently. At some level the amount of investment required will become a significant barrier. What this level is will vary widely, depending on individual farm and farmer circumstances.

However lack of knowledge of the value propositions for improved irrigation management may well be the greatest barrier. Even where there is a general understanding of the value proposition, knowledge of the options available and the skills to implement them may not be sufficiently well developed to capture the value.

1 INTRODUCTION

The National Policy Statement for Freshwater Management 2017 (NPS-FM) requires all regional councils and unitary authorities to set limits on all forms of water use to achieve aquatic ecosystem and human health objectives. If current use, or allocations, in aggregate exceed the relevant limit they must be reduced to comply with the limit within a set time frame.

In some catchments, or freshwater management units, water use has already been judged to be over-allocated in terms of total nutrient loss to water. Examples include the Selwyn-Waihora and Hinds Zones in Canterbury.

Farmers in over allocated areas are having to reduce nutrient loss to water by a prescribed percentage of their baseline loss to water. In some areas this is now a regulatory requirement. In other areas voluntary reductions are being encouraged through education, training and commercial or peer pressure.

Nitrate leaching to groundwater is a significant pathway for N-loss to both groundwater and surface water in intensively farmed areas, particularly if they are irrigated.

This raises three important questions:

Q1 How much can drainage and the associated N-loss to water be reduced by increasing irrigation efficiency?

Q2 What changes in irrigation systems and their management would be needed to achieve this?

Q3 What are the primary incentives and barriers to achieving the changes required?

The objective of this project was to answer these questions in a case study based pilot project. The case study involved twelve dairy farms located in Canterbury, all of which are irrigated using centre-pivot irrigators. The key outputs sought were:

- Quantitative estimates of the reductions in N-loss to water that are achievable on the case study farms by improving irrigation efficiency.
- Information on the nature and scale of changes to irrigation systems and irrigation management that would be required to achieve these reductions beyond the case study farms and information on what might help or hinder change occurring.

1.1 What is "irrigation efficiency"?

There are many different definitions for the generic term "irrigation efficiency". For the purposes of this project we assumed it to be "Irrigation application efficiency". This is the ratio of the volume of water retained in the plant root zone, after drainage has ceased, to the volume of water applied to the land surface. Efficiency is calculated for each irrigation event, and typically varies from event to event. When an irrigation application efficiency value is referred to below it refers to the long-run average of the application efficiency's for all irrigation events.

A "rainfall efficiency" can be calculated in the same way.

It should be noted that in NZ drainage from irrigated lands during the irrigation season will always be higher than under non-irrigated conditions, even if the application efficiency is 100% (ie each and every irrigation event generates no drainage). This is because irrigation maintains a higher soil water content during the irrigation season than occurs without irrigation and therefore there is less capacity to store the rainfall that occurs during the irrigation season. If the rainfall amount exceeds this capacity the excess drains, mostly to groundwater. Rainfall efficiency is lowered by irrigation.

1.2 Irrigation rule

Irrigation application efficiency depends on when irrigation occurs and how much water is applied and therefore on how irrigation decisions are made.

It was assumed for this project that the process of determining when to irrigate and how much to apply involved:

- Measuring or calculating soil water content each day.
- Applying an irrigation rule.

The irrigation rule is:

1. Irrigate when the soil water content has dropped below the Irrigation Trigger level, providing the number of days since the last irrigation in this paddock is equal to or greater than the return period. The trigger level is usually expressed as a percentage of the capacity of the plant root zone to hold water (the “size of the bucket”). Current practice is to use a trigger level of 50%. The return period for a centre-pivot irrigator is typically 3 to 5 days. For a travelling irrigator it is typically 8 to 12 days.
2. Apply the amount of water needed to raise the soil water content to the Irrigation Target level. The target level is also expressed as a percentage of the “size of the bucket”.

If the target level exceeds 100%, irrigation will over-fill “the bucket” and the excess will go to drainage. Sometimes this is unavoidable. A number of travelling irrigators, for example, have a minimum application depth and this can result in the target level being greater than 100%. For example, if the soil water holding capacity of the plant root zone is 60mm and the irrigation trigger level is 50% (current practice for avoiding plant production losses) the soil water content when irrigation is initiated will be 30mm. If the minimum application depth is 40mm the irrigation target cannot be less than 117% [(30+40)/60], unless the trigger level is reduced. Of the 40mm that is applied, 30mm remains in the root zone after drainage is complete, resulting in an irrigation application efficiency of 75% (30/40).

2 METHODS

2.1 Overall Approach

The overall approach to the pilot study was to use well-established computer models to simulate irrigation and drainage, pasture production and finally N-loss to water for each of the case study farms under a wide range of irrigation management scenarios. The models were: IrriCalc (irrigation system simulation model) (Bright, 2009), DairyMod (pasture growth model) (Johnson et al, 2008: Johnson 2013), and Overseer^{TM} (nutrient loss model) (Wheeler et al, 2011). IrriCalc provided irrigation application and drainage outputs as daily time series spanning the period 1/7/1972 to 30/6/2016. The irrigation application depth time series was input to DairyMod, which simulated daily pasture growth over the same time period. This was post processed to provide the average annual pasture production. Coupling these models in this way enabled the effect of irrigation management rules on average annual drainage and average annual pasture production to be quantified. The effect of each irrigation management rule on N-loss to water was assessed using Overseer^{TM}. Irrigation management in Overseer^{TM} was set up to exactly match that used with IrriCalc to generate the irrigation application time-series for DairyMod.

There were two main reasons for assessing the effects on pasture production of each irrigation management scenario. First, it provided a means of checking whether (or how much) pasture production is being compromised by the pursuit of higher irrigation efficiency. Second, it provided a means of checking that the average annual pasture production achieved at different levels of irrigation efficiency is consistent with the pasture production data used in the Overseer^{TM} analysis.

The data from the irrigation scenario modelling provided the evidence base needed to answer questions Q1 and Q2 in Section 1 above.

The third question was addressed by using our expert knowledge of irrigation systems and their operating requirements in conjunction with the evidence base to identify any technical impediments and production incentives to improving irrigation efficiency. The scope of this was limited to technical considerations and did not consider sociological aspects of irrigation decision making.

2.2 Case Study Farms

We aimed to analyse twelve case study farms that were pasture-based farm enterprises located on soil types and in rainfall zones broadly representative of those occurring across the Canterbury Plains. Thus farms were sought that had mean annual rainfalls of between 600mm and 800mm, and root zone plant available water (PAW) capacities of between 60mm and 100mm.

Ravensdown and Ballance Agi-Nutrients supplied twelve candidate dairy farms between them for potential inclusion in this study. Overseer^{TM} files were available through these companies for these farms. The combinations of soil PAW class and rainfall zone covered by these farms were assessed. As a result Aqualinc have added two more farms to provide greater coverage of the combinations of PAW and rainfall we were seeking. The following figure shows this coverage. In terms of spatial coverage, the combinations provide good coverage of most of the Canterbury plains. Some of the very deep soils are not represented, but these tend to be less of an issue regarding leaching losses and there are not very extensive areas of these soils on the Plains.

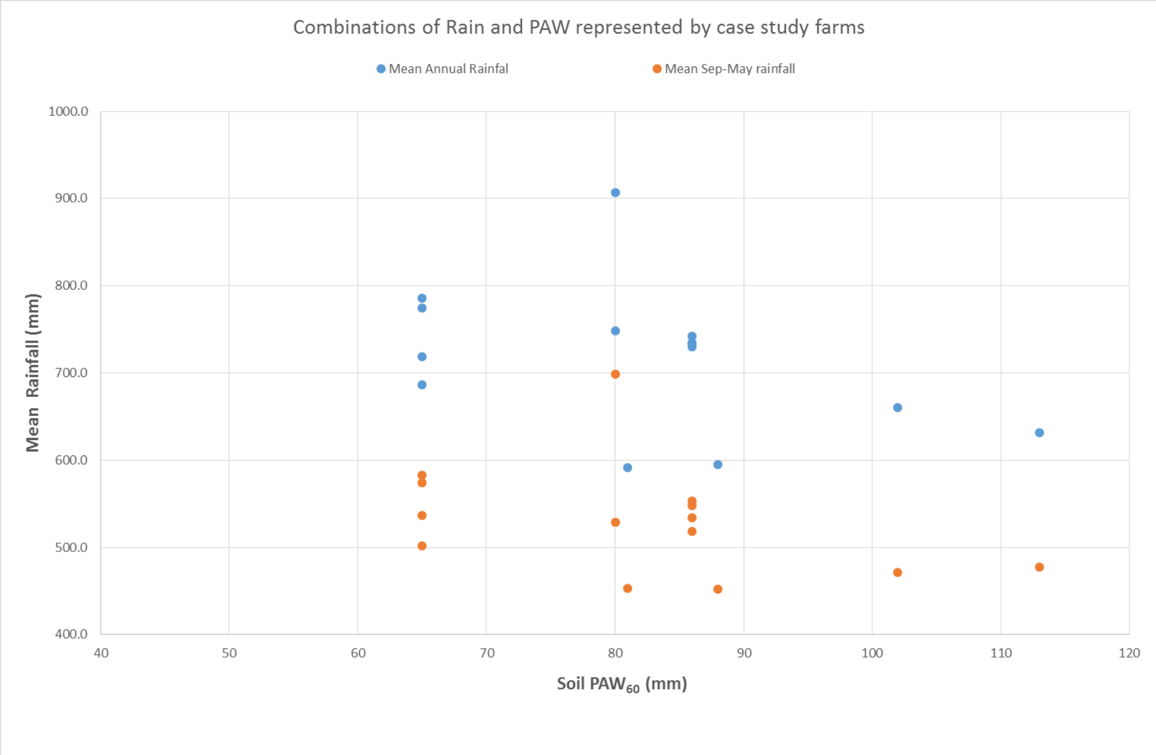

Figure 1: Combinations of annual rainfall and plant available soil water represented by case study farms

2.3 Irrigation management scenarios

There are two main irrigation management parameters to work with to reduce drainage and improve irrigation application efficiency and rainfall efficiency. These are the irrigation trigger level and the irrigation target level. The irrigation management scenarios we analysed were designed to systematically test a wide range of combinations of trigger level and target level – sufficient to traverse the range from a low irrigation application efficiency of 60%, through what is currently considered to be Good Management Practice (from an N-loss perspective) to extremely ‘severe’ deficit irrigation rules that minimise drainage but also compromise pasture production.

The selection of irrigation trigger levels to test was guided by their expected effects on the risk of pasture production loss and drainage risk. The three sets of trigger levels we tested are set out in the following table.

Table 1: Irrigation trigger levels used in the irrigation scenario analysis (% of soil water holding capacity)

Description	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Minimise production risk (Current practice)	50%	50%	50%	50%	50%	50%	50%	50%
Balance risks	20%	40%	50%	50%	50%	40%	30%	20%
Minimise drainage risk	10%	30%	40%	40%	40%	30%	20%	10%

Current practice is to minimise production risk by setting the irrigation trigger level so that there is a very low risk that pasture would experience sufficient soil moisture stress to reduce production (assuming sufficient irrigation system capacity and a very reliable supply of water). Typically this trigger level is 50% of the PAW. Current practice is to use this value throughout the irrigation season.

The two alternate trigger level regimes aim to reduce the risk of drainage occurring by recognising that in the shoulders of the irrigation season the probability of rainfall is higher than in summer and the evapotranspiration rates are lower. The combined effect of these was expected to be lower risk of pasture production loss, even if the trigger level was set lower than current practice. The ‘balance risks’ trigger levels are based on Hoffman et al (1990) and attempt to achieve a better balance between the risk of production loss and risk of drainage, compared to current practice. The ‘minimise drainage risk’ trigger levels are uniformly lower than the ‘balance risks’ levels and were set at a level that was expected to reduce average annual pasture production.

The irrigation target levels used to create the irrigation management scenarios ranged from 140% down to 55% of PAW. The combination of irrigation trigger at 50% of PAW and irrigation target of 140% of PAW results in an average modelled irrigation application efficiency of 55.6%. At the other extreme, the combination of irrigation trigger at 50% of PAW and irrigation target of 55% of PAW results in an application depth of only 5% of PAW (5mm for a soil PAW of 100mm). After each irrigation application the soil water deficit would be 45% of PAW, which leaves significant capacity to store rainfall (45mm for a soil PAW of 100mm). The range of irrigation target levels modelled therefore cover the spectrum from very low irrigation application efficiency to 100% irrigation application efficiency (modelled) <u>and</u> very high rainfall efficiency.

For each of the case study farms we used IrriCalc to model the effects of the many different irrigation management scenarios defined by the combinations of irrigation trigger and target levels on drainage and irrigation over the period 1972 – 2016. The soil-water model built into the current version of IrriCalc does not simulate bypass flow. Therefore if the irrigation target equals 100% of PAW, no drainage is generated and the application efficiency is 100%. If the target is greater than 100% of PAW, drainage is generated and the application efficiency is less than 100%. The application efficiency can never be greater than 100% - all targets of less than 100% of PAW result in an application efficiency of 100%. Irrigation practices that have a target of less than 100% of PAW are referred to as ‘deficit irrigation’ practices because a soil water deficit remains after each irrigation event. One reason for leaving a soil water deficit after an irrigation event is to leave capacity in the soil to store rainfall that might occur after the irrigation event.

Two other factors that affect irrigation management decisions are irrigation system capacity, an irrigation design parameter, and water supply restrictions. System capacity affects irrigation management decisions through its effect on the irrigation return period. Irrigated dairy farms in Canterbury typically have system capacities that are sufficient to fully meet irrigation need 9 years in 10, on average, and meet a significant proportion of the irrigation need in the shortfall year. We assumed that irrigation system capacity did not adversely affect irrigation management for the case study farms. Irrigation water supplies can be restricted due to equipment failure, electricity supply failure or through take restriction conditions in a resource consent. Exploring the effects on irrigation strategy and drainage of water supply reliability limitations was beyond the scope of this pilot study so we assumed 100% water supply reliability. It should be noted, however, that a common response to limitations in system capacity or water supply reliability is to raise the irrigation trigger and target levels to maintain higher soil water contents than would otherwise be the case. A consequence of responding this way is increased average annual drainage and thus N-loss to water, all other things being equal.

2.4 Primary input data

The soil properties data required as inputs to IrriCalc and DairyMod were obtained from S-Map fact sheets (and matched those used for the Overseer^{TM} analysis) and in Lilburne et al (2013). These included soil horizon specific data as well as root zone PAW.

Daily rainfall and reference crop evapotranspiration time-series were developed by Aqualinc for the virtual climate station grid square that best matched each case study farm, using methods described in Kerr (2017). The balance of the climate data required for DairyMod was sourced from NIWA's online climate data portal.

The crop coefficient time-series used for grazed irrigated pasture was derived from Van Housen's (2015) analysis of data collected through Canterbury Regional Council's lysimeter network.

All data inputs required for the Overseer^{TM} analyses was supplied by Ravensdown or Ballance Agri-Nutrients as Overseer^{TM} XML files.

3 EFFECTS OF IRRIGATION MANAGEMENT ON N-LOSS TO WATER

Quantifying the effects of irrigation management on N-loss to water proceeded in stages, as outlined in the previous section. We first examined the effects of a wide range of irrigation management scenarios on average annual drainage, as a key determinant of N-loss to water. We then tested the effects of irrigation management on pasture production to determine when the pursuit of low-drainage irrigation management began to adversely affect pasture production. From this information we selected an irrigation trigger level strategy and then systematically explored the effect of different irrigation target levels on N-loss to water using Overseer^{TM}.

3.1 Effects of Irrigation Management on Drainage

There are two distinct phases in the rate at which drainage is reduced as the irrigation target level reduces. In the first phase irrigation application efficiency increases as the irrigation target reduces towards 100% of PAW from a target level perhaps much greater than 100% – the proportion of the irrigation amount that drains during each irrigation event reduces as the application depth reduces. Once irrigation application efficiency reaches 100% (ignoring potential by-pass flow effects) it can't increase any further. Then, as the irrigation target level reduces below 100% of PAW we move into the second phase of drainage reduction. This phase can be thought of as the phase in which rainfall efficiency is increased as the irrigation target level reduces.

As the application depth reduces below that which would exactly eliminate the soil moisture deficit at the time of irrigation, capacity for storing rainfall increases and thus the amount of drainage from rainfall events occurring during the irrigation season reduces, thus increasing rainfall efficiency.

The following graph shows the effect of the irrigation target on drainage for one of the case study farms. In particular it shows the effects month by month.

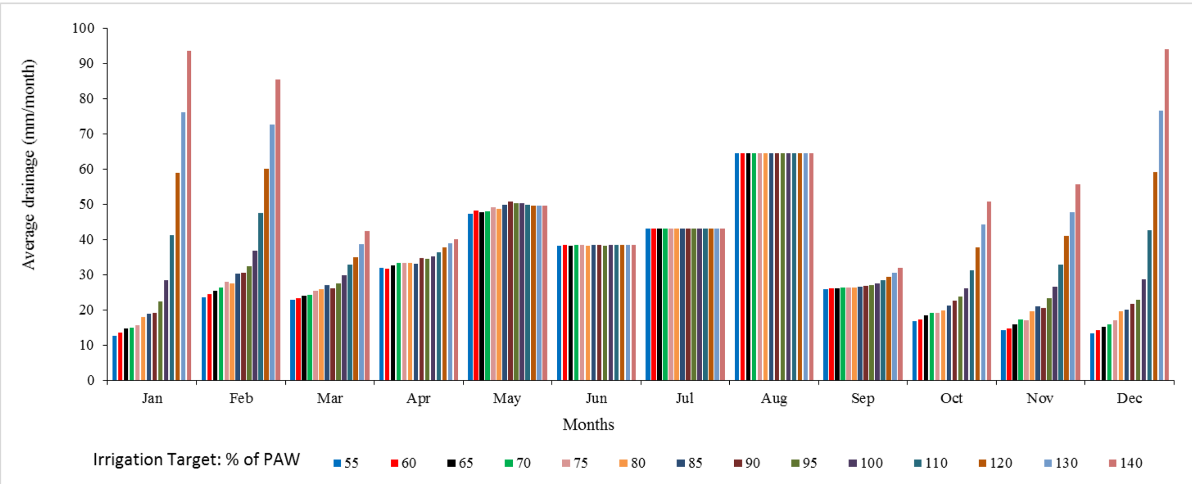

Figure 2: Effect on average monthly drainage of the irrigation target (% of PAW) for one case study farm

Irrigation management is seen to have no effect on the monthly average drainage in June through August because our irrigation rule prevents irrigation in these months and any 'carry-over' effects of irrigation have been fully expressed by the end of May. The following graphs therefore report average total drainage over the months September through May.

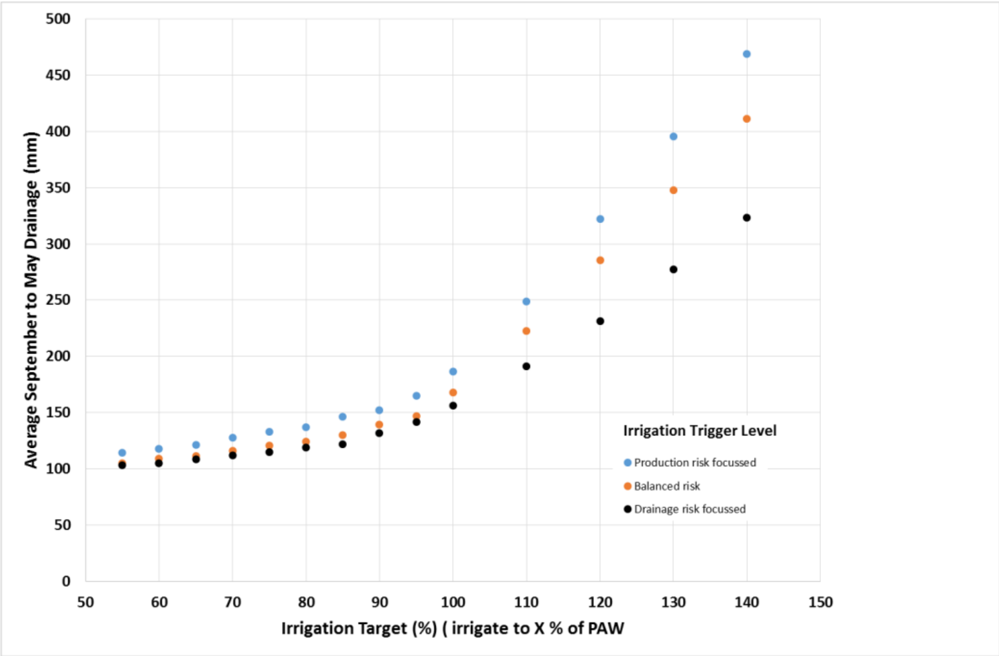

Figure 3: Effect of Irrigation Trigger Level on Average September to May Drainage for one case study farm

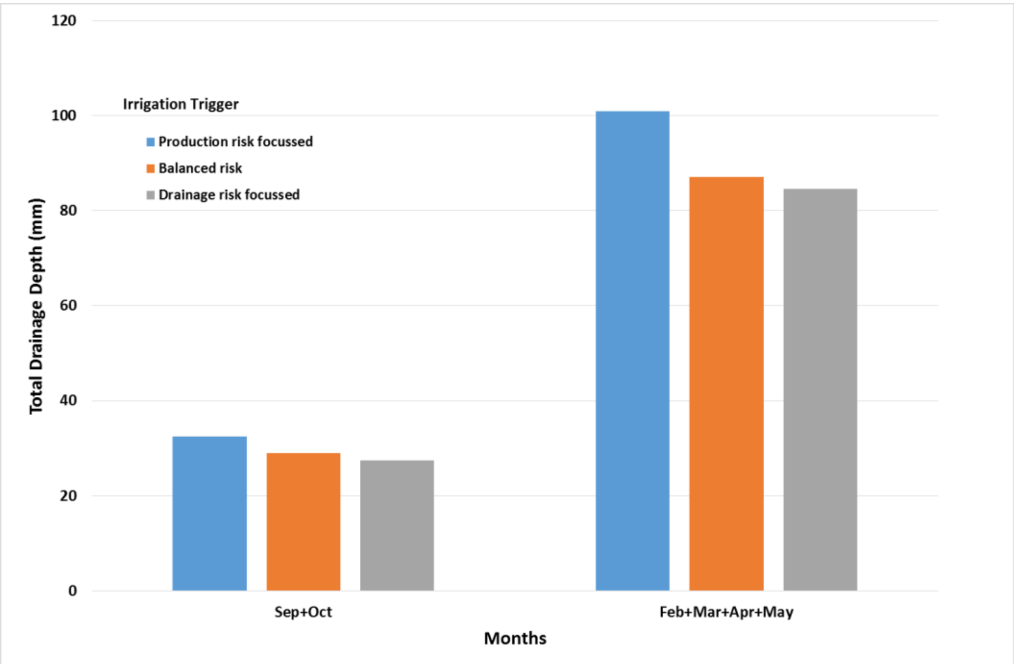

Figure 4: Effect of Irrigation Trigger Levels on average drainage depth for time periods in which trigger levels differ

The irrigation trigger levels differ only in the months of September, October, February, March and April. The aim of the changes to the trigger levels in these months is to reduce drainage during the shoulders of the irrigation season. Figure 4 shows the effect of the trigger levels on the average drainage depth for these periods. These data are for one case study farm and the irrigation target is 100% of PAW. Most of the reduction in drainage achieved by changing the trigger levels from current practice occurs in late summer and autumn.

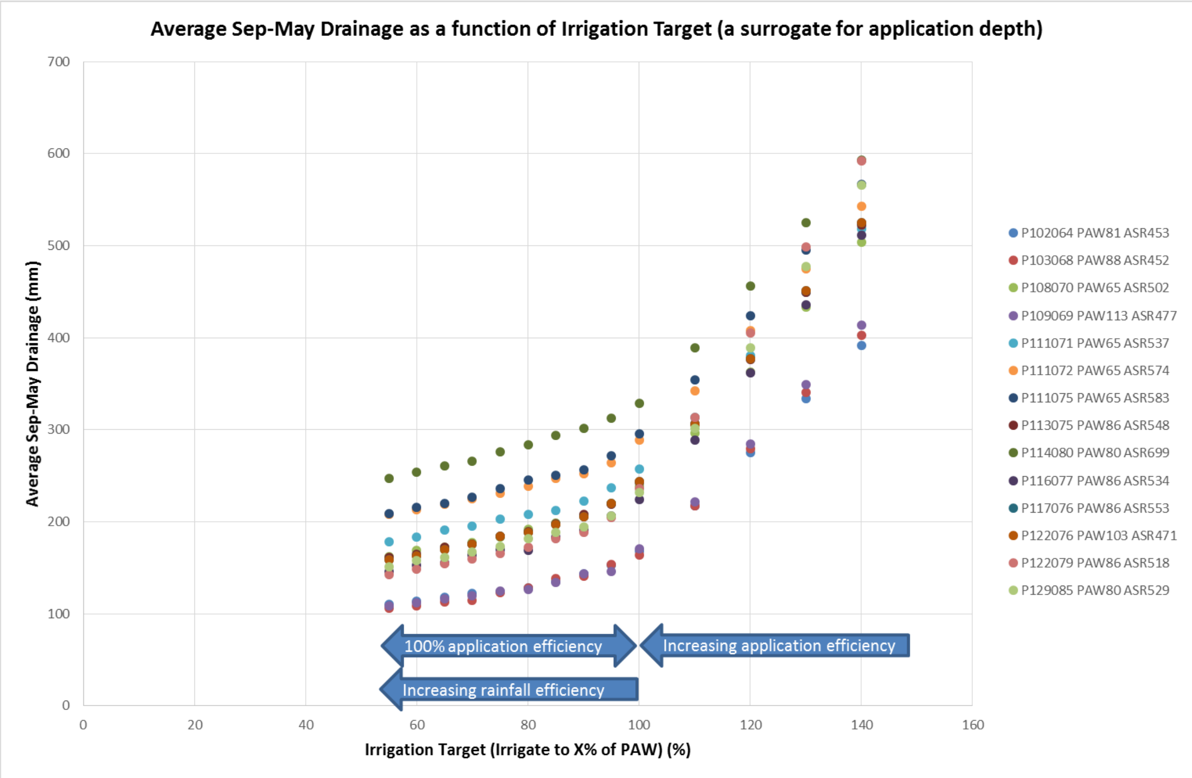

Figure 5: Effect on September to May drainage of irrigation target for all case study farms

These data have been normalised by dividing the drainage depth for each farm by the drainage depth that you get when the irrigation target is 100% of PAW – that is, when the application depth exactly matches the soil moisture deficit at the time of irrigation. The following graph show the results of this normalisation.

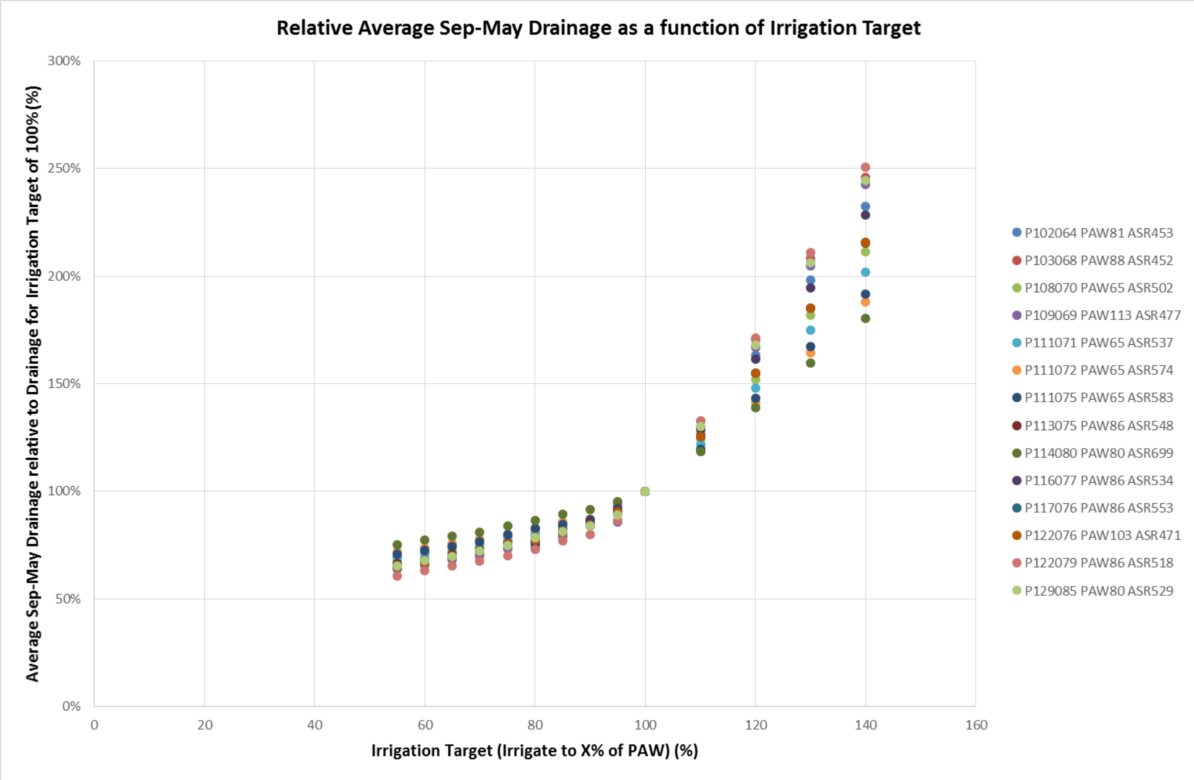

Figure 6: Normalised September to May drainage as a function of irrigation target, for all case study farms

These graphs demonstrate that substantial reductions in drainage can be achieved by reducing the irrigation target soil water content to 100% of PAW, thus increasing the modelled irrigation application efficiency to 100% (this is reached in the modelled scenarios when the irrigation target is 100% of PAW).

The rate of reduction in drainage with reducing irrigation target declines as the irrigation target decreases below 100% of PAW. That is, reducing drainage by increasing rainfall efficiency is more difficult than by increasing irrigation application efficiency.

The influence of soil PAW and rainfall on drainage becomes much less once the irrigation target drops below 100% of PAW, as indicated by the tighter clustering of data points.

The current Good Management Practice for irrigation, from a water allocation perspective, aims to achieve an irrigation application efficiency of 80%. This is equivalent to setting the irrigation target at about 112% of PAW, assuming an irrigation trigger of 50%.

Reducing the irrigation target to 100% of PAW from this GMP point is expected to reduce the average September to May drainage by about 20%, depending on the PAW and rainfall. If the irrigation target is reduced still further, for example to 80% of PAW, the average September to May drainage on these case study farms is reduced 30% to 40% below that at GMP.

It is clear from these graphs that significant reductions in drainage can be achieved by dropping the irrigation target to a value of less than 100% of PAW (i.e. deficit irrigating).

3.2 Effects of Irrigation Management on Pasture Production

There is a very large number of combinations of irrigation trigger and irrigation target levels that are feasible. To make the analysis tractable we took the approach of defining three sets of irrigation trigger levels and for each, analysed a wide range of irrigation target levels.

The irrigation trigger levels were chosen to provide a range from production focussed to drainage focussed, and a 'balanced' middle ground. The production focussed trigger level is current practice. Given the rationale behind the other sets of trigger levels, one would expect they'd have some effect on average annual pasture production.

The effect of the three sets of trigger levels is illustrated in the following figure which uses results from one case study farm.

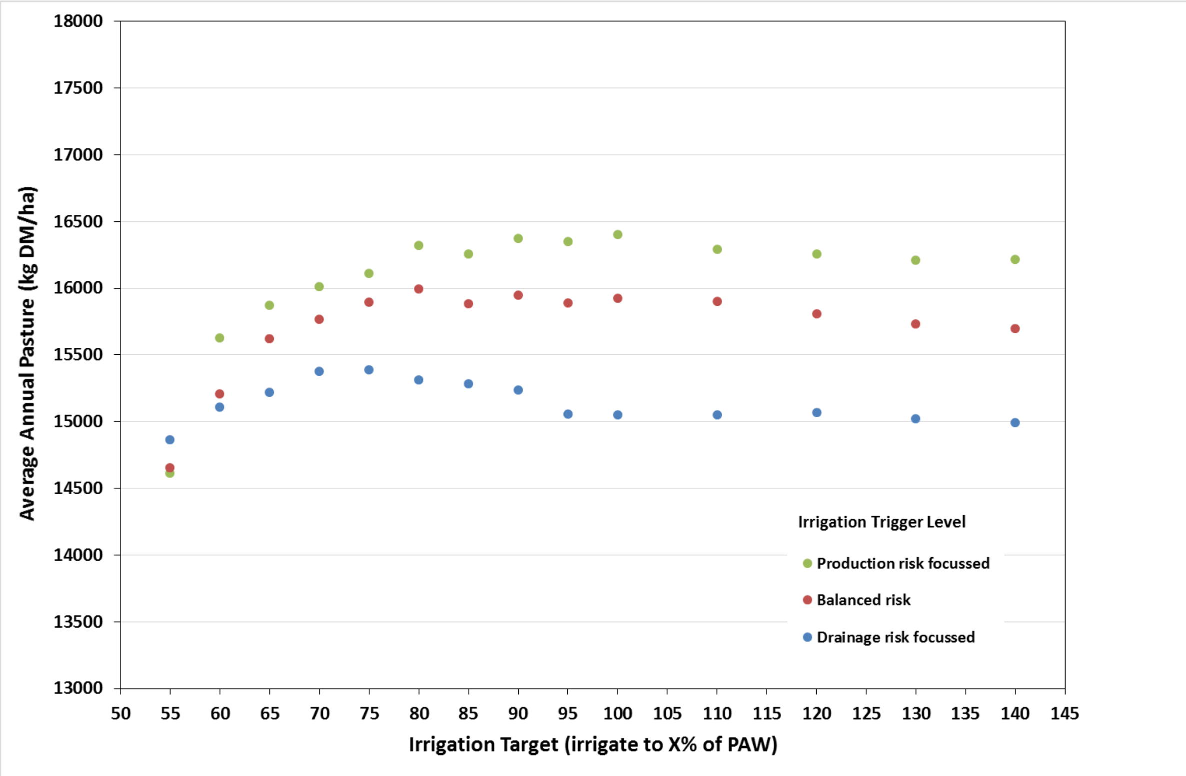

Figure 7: Effect of Trigger Level on Average Annual Pasture Production for one case study farm

Both sets of irrigation trigger levels that are alternatives to current practice (production risk focussed) reduce average annual pasture production. In the case of the 'balanced risk' trigger level in the above figure, pasture production is 2% to 3% lower than under current practice across most of the irrigation target levels analysed. For the more severe trigger level set (drainage risk focussed) the pasture production is 6% to 8% lower than under current practice.

Given the relatively small reduction in average annual pasture production, the pasture production results presented below are focussed on reporting the effect of the irrigation target level used in conjunction with the 'balanced risk' trigger level set, for each of the case study farms. In each case the average annual pasture production has been normalised by dividing it by the average annual pasture production achieved using an irrigation target of 100%.

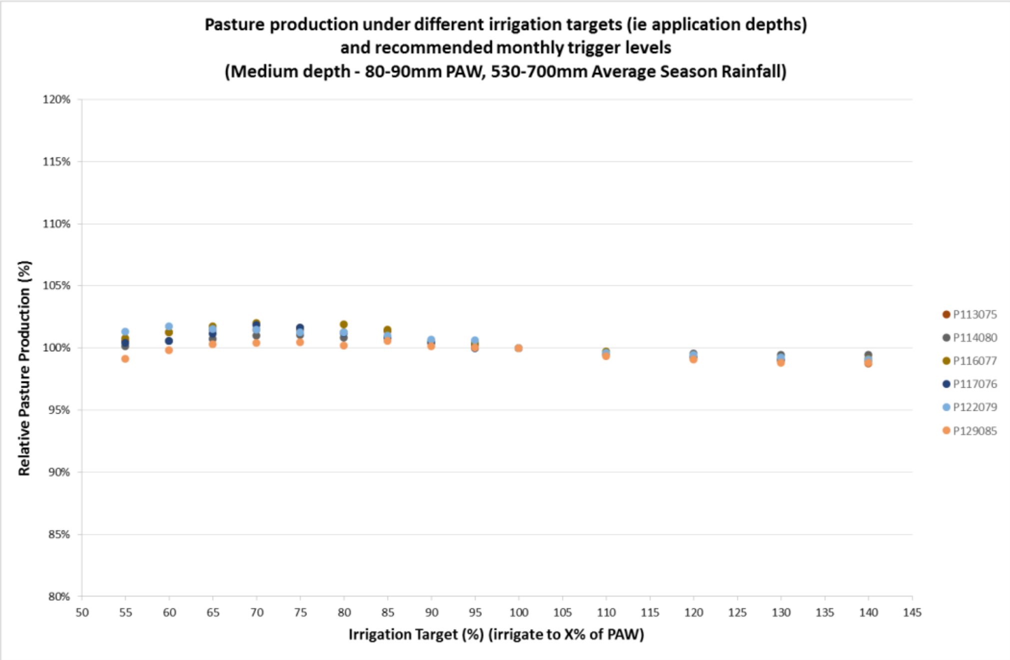

Figure 8: Effect of irrigation target on pasture production for farms on medium soils and with 530-700mm average seasonal rainfall.

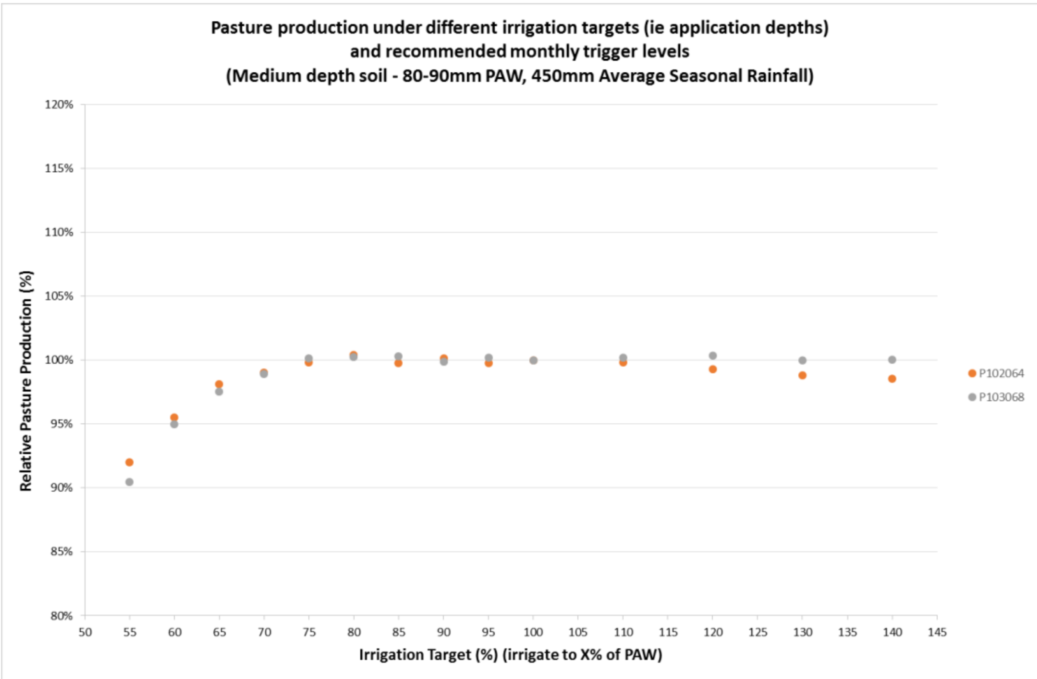

Figure 9: Effect of irrigation target on pasture production for farms on medium soils and with 450mm average seasonal rainfall

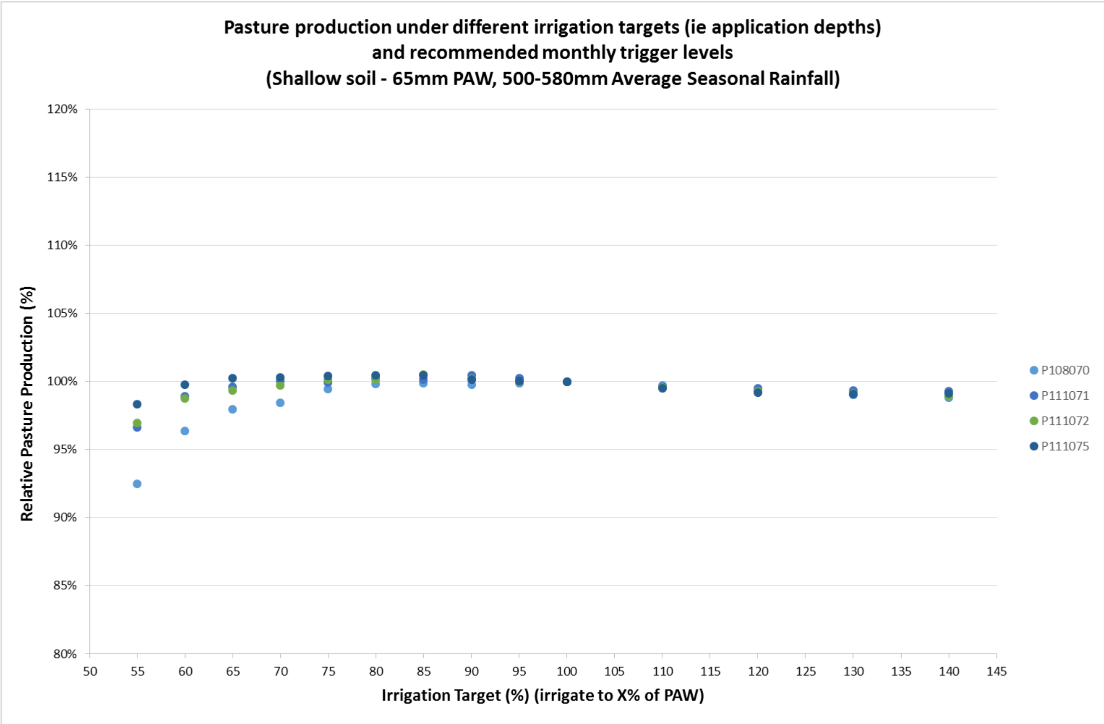

Figure 10: Effect of irrigation target on pasture production for farms on shallow soils with 500 – 580mm average seasonal rainfall.

These results demonstrate that for these farms there is little variation in pasture production as the irrigation target drops from 140% down to about 75%. For the shallower soils or drier climates, dropping the irrigation target below 75% reduces pasture production to an increasing degree.

However, as the target is reduced the risks associated with not being able to irrigate increase. If, for example, the irrigation target is 80%, the trigger is 50% and the root zone PAW is 50mm. These parameters result in an irrigation application depth of 15mm. Under typical Canterbury summer conditions irrigation will need to be occurring every three days to keep up with evapotranspiration. If the irrigator breaks down at the end of its run it needs to be fixed in three days to prevent soil moisture stress occurring. If the target was 60% the application depth would be five millimetres and irrigation would need to occur every day. There would be no lee-way to cope with equipment breakdowns, for example. Many centre pivots irrigating light soils operate on a 50% trigger and 15mm every three days regime. This suggests that the level of risk associated with an irrigation target of 80% of PAW is acceptable.

In light of Figures 7 to 9, this can be interpreted as pursuing the objective of minimising drainage by reducing the irrigation target, subject to not reducing average annual pasture production.

An alternative objective would be to maximise production per unit of drainage. The following figure shows the effects on both pasture production and production per unit drainage of changing the irrigation application depth. It indicates that production per unit of drainage is maximised at a lower irrigation target than the irrigation target at which production just starts to reduce. While pursuing this objective would result in lower drainage than the previous objective, the financial risks associated with it are likely to be higher.

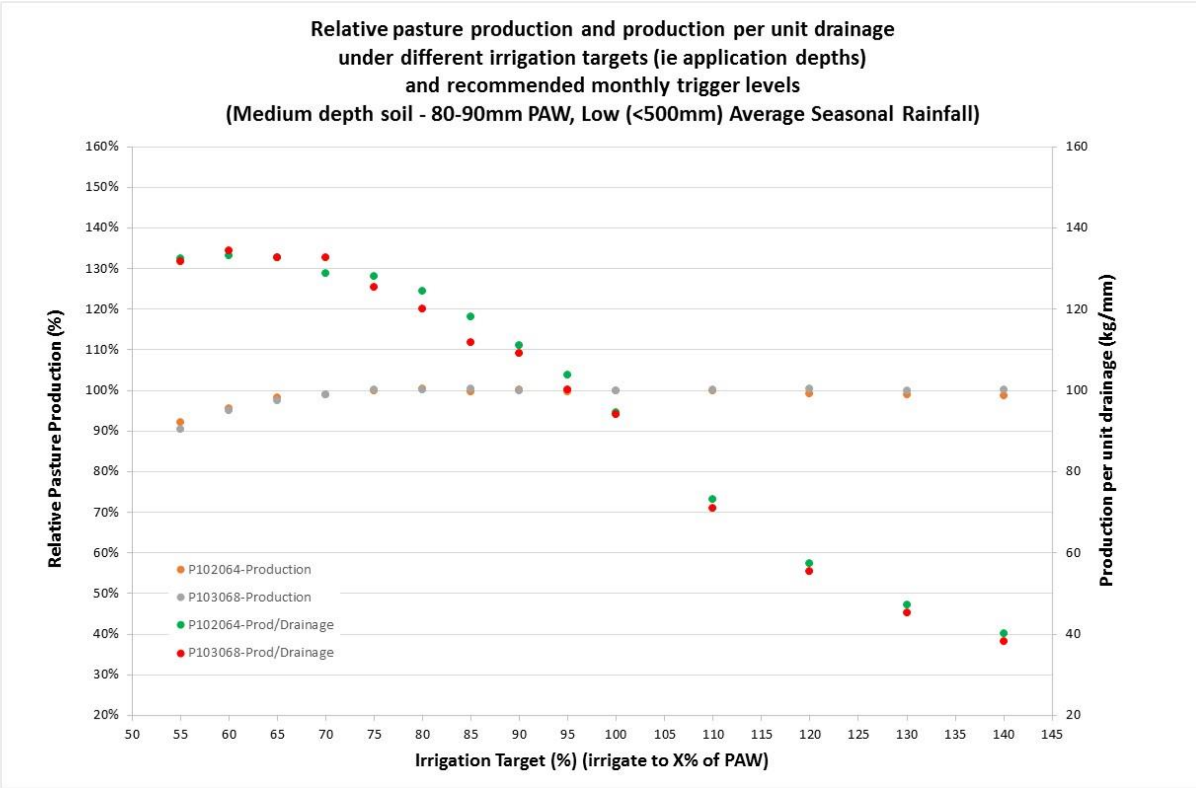

Figure 11: Effect of irrigation target on pasture production per unit drainage.

The results of the drainage and pasture production analyses suggest that there is benefit, in terms of reducing drainage, in reducing the target irrigation application depth to 80% of PAW and that this can be done without adversely affecting average annual pasture production, for a given trigger level set.

3.3 Effects on N-Loss to water

The effects on average annual N loss to water of changing irrigation management has been modelled using Overseer^{TM} for the ten farms for which we received Overseer^{TM} files. No changes were made to the Overseer^{TM} files supplied, apart from changing the irrigation management rules.

The analysis assumed the use of the balanced risk trigger level set because of the drainage reduction it achieves at very small cost in terms of average annual pasture production.

The following graphs show the results, grouped by soil PAW.

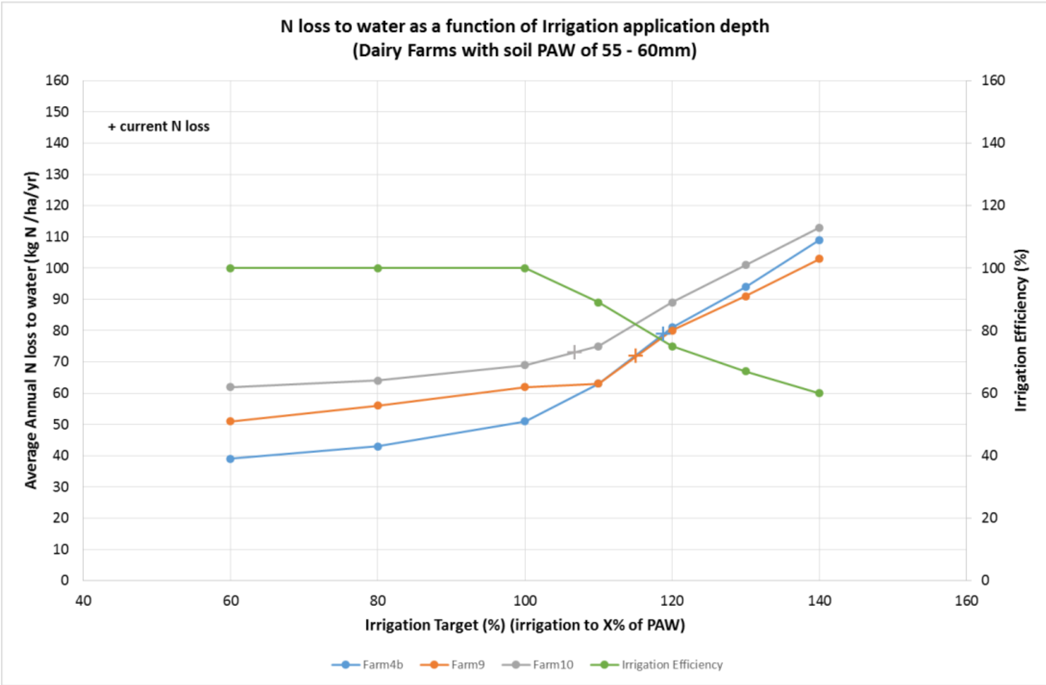

Figure 12: N-loss to water as a function of irrigation target – shallow soils

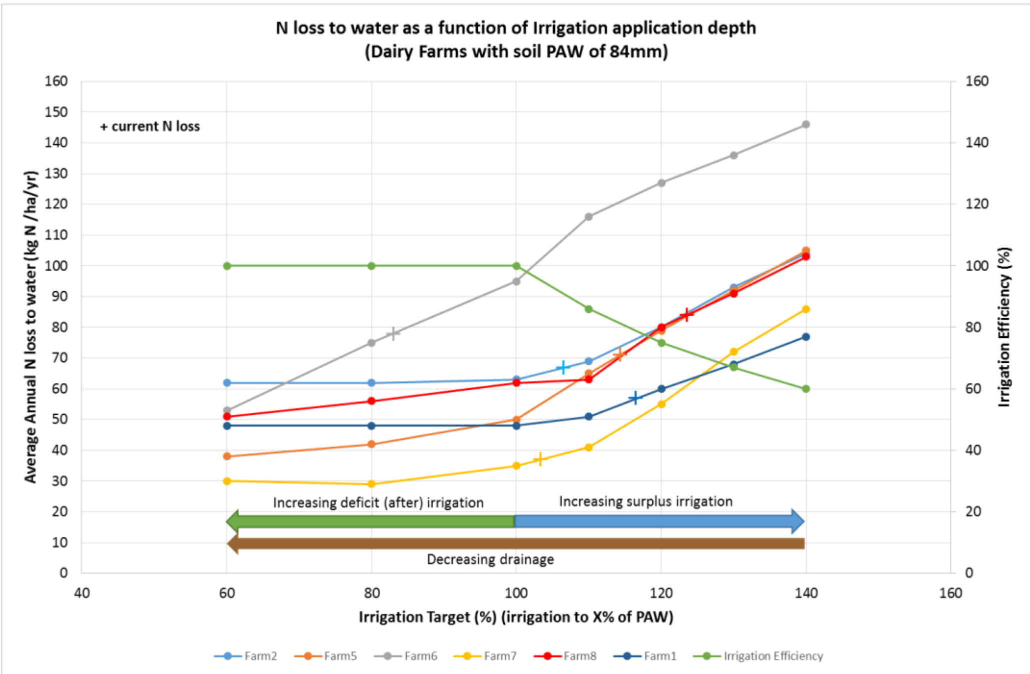

Figure 13: N-loss to water as a function of irrigation target – medium soils

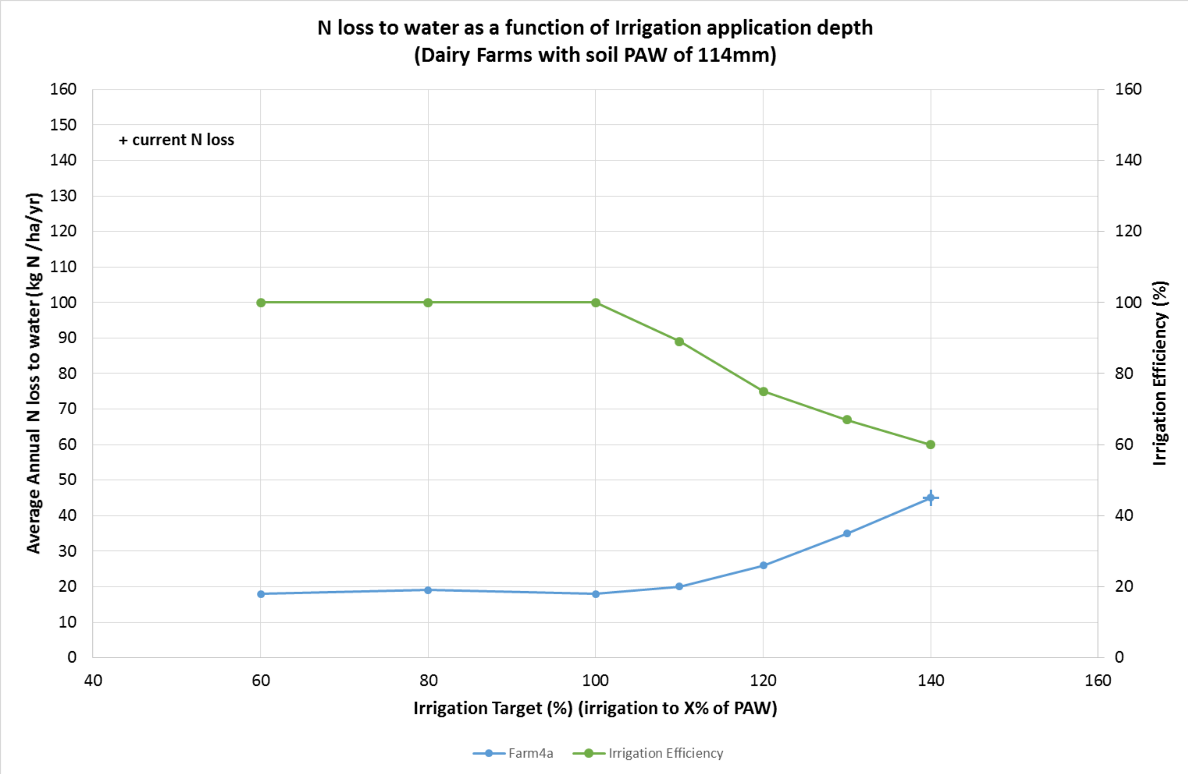

Figure 14: N-loss to water as a function of irrigation target – deep soil

Leaving aside the obvious variation between farms, the pattern of reducing N loss as the irrigation target is reduced follows the same pattern as reducing drainage – as one would expect.

N loss reduces relatively quickly as the irrigation target reduces from 140% to 100% of PAW. This corresponds to increasing irrigation application efficiency from 60% to 100%.

N loss reduces at a lower rate as the irrigation target decreases below 100% of PAW. There is a notable difference between soils in this regard: for deeper soils (in this case 114mm PAW) there is no reduction in N loss as the irrigation target decreases below 100% of PAW whereas there continues to be some decrease for medium soils and a worthwhile decrease for light soils.

Based on these case studies, almost all of the gains in terms of N loss reduction are achieved by using an irrigation application depth that refills the soil profile to 80% of PAW. The irrigation trigger level set (i.e. soil moisture content as a % of PAW at which irrigation is initiated) used in these analysis was the balance risk set in which the trigger varies from month to month as follows:

Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
20%	40%	50%	50%	50%	40%	30%	20%

The average annual pasture production graphs show that with these trigger levels and an irrigation target of 80% of PAW there is only a minor production penalty on average, relative to the current practice trigger level of 50%. Note that these trigger levels differ significantly from current practice during the 'shoulders of the season'.

The extent to which the modelled N-losses to water are reduced from current levels by applying this irrigation strategy depends on what the current levels are. To get a sense of this the current Overseer™ modelled N-loss to water values obtained using the input file as supplied are shown in the N loss graphs above on each farm's N loss curve.

3.4 Potential N-loss Reductions on Case Study Farms

For most farms, important (given they're located in Canterbury) reductions in N-loss to water are achievable by varying the irrigation trigger level and adopting an irrigation target that leaves a soil moisture deficit after each irrigation event. The recommended irrigation target, based on these results, is 80% of PAW. The reductions in N-loss to water achieved by making these changes to irrigation management are summarised in the following table.

Table 2 Modelled potential N-loss reductions on the case study farms:

Farm	Current N Loss	N Loss with 'optimum' irrigation	N loss Reduction	
	(kg N /ha/yr)	(kg N /ha/yr)	(kg N /ha/yr)	(%)
1	57	48	9	16%
2	67	62	5	7%
3	131	92	39	30%
4a	45	19	26	58%
4b	79	43	36	46%
5	71	42	29	41%
6	78	75	3	4%
7	37	29	8	22%
8	84	56	28	33%
9	72	56	16	22%
10	73	62	11	15%

As noted above, these modelled N-loss reductions are based on the use of an irrigation trigger level that varies from month to month and a constant irrigation target of 80% of PAW. This means that the irrigation application depth varies from month to month because the depth is a function of the difference between the trigger level and the target.

In practice most farmers find it simpler to operate on a fixed-depth basis. Thus the trigger level would vary from month to month, following the 'balanced' trigger levels, and the application depth would be fixed. This depth would be set so that in summer it did not raise the soil water content above the 80% target as recommended. Fixing the application depth means that the target would vary from month to month, as the trigger level varied. In the shoulders of the irrigation season the target would be less than 80% of PAW, assuming typical application depths, thus providing more capacity to store rainfall. The N-loss reductions would potentially be greater than those shown above – further analysis is required to test this, and assess effects on production.

4 TECHNICAL REQUIREMENTS, BARRIERS AND INCENTIVES

The irrigation management strategy that achieved the N-loss reductions reported in Section 3 requires the following:

- Soil water content is routinely measured using properly installed, good quality soil moisture sensors or a reputable soil moisture monitoring service provider.
- The irrigation application system can be adjusted to apply relatively small amounts of water (e.g. 15mm). The depth depends on the soil water holding capacity. The larger this capacity is the higher the application depth can be, which increases the range of irrigator hardware options available.
- The irrigation application system has a relatively short return period (e.g. 3 days). This depends on the amount of water applied and the evapotranspiration rate. The higher the application depth (which is a function of soil water holding capacity) the longer the return period can be.
- The irrigation water supply is very reliable.

These operating requirements are similar to those required to meet the irrigation management criteria specified in Canterbury Regional Council's Plan Change 5, except for last point above on water supply reliability.

The extent of the changes required to meet these operating criteria have been assessed using recent mapping of the area actually irrigated in Canterbury and the types of irrigation system used for each irrigated area (Brown, 2016). This information has been used in conjunction with mapped soil properties to estimate the area for which some change to the irrigation system is likely to be required to implement the irrigation management strategy used for the Overseer^{TM} analysis reported in Section 3. The scale of change is summarised in the following table.

Table 3: Current area irrigated in Canterbury by irrigation system type and area potentially requiring irrigation system change.

Irrigation Method	Total area (ha)	% of Irrigated area	Area to upgrade	Upgrade area as % of Irrigation Method area
Centre-pivot	222,618	52.6	0	0
Linear (lateral) move	31,110	7.4	5,241	16.9
Drip/micro	2,437	0.6	0	0
Solid set	3,911	0.9	0	0
Roto-rainer	80,442	19.0	56,506	70.2
Linear boom	9,678	2.3	1,431	14.8
Gun	30,408	7.2	17,087	56.2
K-line/Long lateral	42,088	10.0	39,475	93.8
Side Roll	253	-	154	60.9
Total Area	422,945		119,894	28.4

At present about 72% of the area currently irrigated in Canterbury is very likely to be able to meet the above application depth and return period requirements. An additional 19% may be able to meet these criteria but would require a comprehensive irrigation design review and capital investment in irrigation equipment, this costing between \$1100/ha and \$1400/ha. The balance almost certainly require replacement of the existing irrigation system, the cost of which is likely to be in the range \$3300/ha to \$4800/ha.

A recent survey (Curtis, pers com) of irrigation management practices indicates that in the area surveyed about 60% of properties have soil moisture sensors installed but that fewer than half of these are actually used to guide day-to-day irrigation decision making.

The main incentives for changing irrigation management practices are economic and regulatory.

The rapid increase in the use of centre pivot irrigators over the past fifteen years has largely been driven by the production increases achievable through being able to irrigate 'little and often' and reductions in labour input, compared to more traditional alternatives. Improvements in irrigation efficiency that are achievable through using centre-pivot irrigation equipment (or equivalent) might be expected to reduce operating costs (less energy used for pumping) and thus incentivise irrigation efficiency improvements. However the size of the fixed-price component of electricity costs often means the reduction in operating costs is modest.

Given the low reported actual use of soil moisture monitoring technology as a regular source of data for irrigation management, it appears that the value proposition for improving irrigation management is either not sufficiently compelling to justify expenditure of money and management effort on it, or it is not understood.

Regulatory-based incentives to improve irrigation efficiency stem from the implementation of limits on irrigation water use and nutrient discharge. Limits on irrigation water use are typically based on the assumption that irrigation efficiency is 80% or better. Operating at less than 80% efficiency has a high economic cost if irrigation is forced to stop once the seasonal water use limit has been reached – operating as a dryland dairy farm in Canterbury from mid-January onwards, for example, either drops production or increases feed costs substantially. Mandatory reductions in Nitrate loss to water will require changes in land and water management. The results above indicate that changes in irrigation management can, in many cases, contribute significantly to meeting the mandated reductions. The results suggest that N-loss reduction may provide a stronger business case for improving irrigation management than does reducing energy costs.

Capital investment is likely to be required on a significant number of farms in order to reduce N loss through using irrigation water and rainfall more efficiently. At some level the amount of investment required will become a significant barrier. What this level is will vary widely, depending on individual farm and farmer circumstances.

However lack of knowledge of the value propositions or business cases for improved irrigation management may well be the greatest barrier. Even where there is a general understanding of the value proposition, knowledge of the options available and the skills to implement them may not be sufficiently well developed.

5 CONCLUSIONS

Overseer™ modelled N-loss to water can be reduced by 27% (~19 kg N/ha/year), on average, by changing irrigation practices to make more efficient use of both irrigation water and irrigation-season rainfall on the twelve case study farms analysed in this pilot. The percent reduction ranges from 4% to 58%. These reductions in N-loss to water can be achieved without significantly reducing modelled average annual pasture production.

Changes to both the irrigation trigger level and the irrigation target level are beneficial for making more efficient use of irrigation water and rainfall.

Changes to the irrigation trigger level have more effect on average annual pasture production than do changes to the irrigation target level, unless the target level is reduced to less than about 70% of PAW. Care should therefore be exercised around the setting and application of the trigger level.

Regular soil moisture measurements are essential to ensure that the soil water content does not drop below the irrigation trigger level in order to reduce the risk of pasture production losses.

Further refinement of the irrigation rule may lead to lower N-loss to water estimates than those presented in this report and eliminate the current (very small) reduction in pasture production – the huge number of possible combinations of irrigation trigger and target have not been exhaustively tested.

A high proportion of the irrigation systems on the Canterbury plains are capable of being managed according to the irrigation strategy developed through this pilot study. Greater understanding of the value proposition of changing to this strategy is a key to reducing N-loss to water.

6 ACKNOWLEDGEMENTS

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