Modelling water irrigation management approaches for economic and environmental benefits

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KEY FINDINGS

Using soil moisture as a trigger for irrigation can achieve better water-use efficiency without compromising pasture growth. The ability to control soil moisture using improved irrigation scheduling has positive environmental and economic outcomes.

No single soil moisture level simultaneously maximises pasture growth, minimises water losses from the root zone and minimises financial costs, especially when dealing with uncertain weather. Farmers and policymakers should understand the competing pressures to manage irrigation and make decisions that consider all these pressures.

Utilising policy to incentivise farmers to move towards more water-efficient irrigation practices could prove valuable to farmers. However, no one irrigation approach is best suited to every operation. Instead, policy should aim to improve irrigation performance while considering possible constraints and differences, such as water supply reliability or irrigation infrastructure constraints.

BACKGROUND

Dairy farms make up 59% of all the irrigated area in New Zealand (NZ), with one out of seven dairy farms in the country receiving irrigation.[1] Irrigation has provided land-use flexibility, as such, there has been an expansion in dairying, particularly in Canterbury, where the number of dairy cattle increased 31% between June 2011 and June 2018.[2]

The increase in irrigated land area in Canterbury has placed irrigation management under increasing scrutiny from regulators and the public. This new scrutiny has contributed to a change in irrigation systems, with a dramatic shift from inefficient systems such as flood irrigation to more efficient spray systems, along with a drive to manage irrigation more efficiently. Both land and water regional policies[3] and industry-led initiatives (such as the Matrix of Good Management[4]) address irrigation efficiency and seek irrigation practices that result in better utilisation of nutrients by pasture and reduced nutrient loss from the root zone to surface and ground water.

This policy brief compares typical, good and best irrigation management practices (TMP, BMP and GMP, respectively; Table 1) in dairy farms for their environmental (water used and loss of water from the root zone) and economic (financial and pasture production) outcomes. While this brief is not a comprehensive comparative analysis of TMP, GMP and BMP, it does provide insights into the relative economic and environmental performance of various irrigation management practices. Our aim is to provoke a discussion on the importance of quantifying the potential costs and benefits of different irrigation management practices to help enhance future policy discussions.

CURRENT WATER IRRIGATION MANAGEMENT PRACTICES

Empirical data for actual irrigation practice come from the 2017 Survey of Rural Decision Makers (SRDM; Box 1).[5]

Box 1: Survey of Rural Decision Makers

The SRDM is an extensive, internet-based survey that covers both commercial production and lifestyle farms in all 16 regions of New Zealand. The 2017 survey included approximately 225 questions on topics ranging from demographics, values and environmental preferences, to land use, future intentions and adoption of agricultural technologies. Notably, it also included a series of questions pertaining to irrigation practices.

The strategy used to sample survey respondents relied primarily on official farmer registries, industry and sector group membership lists, and individuals who responded to the 2013 and/or 2015 SRDM. Approximately 4,500 people completed the 2017 SRDM, evenly split between commercial and lifestyle farms. Among the 2,393 commercial farmers who completed the survey, 459 (19%) reported having a water irrigation system (no effluent irrigators included), 175 (38%) of whom resided in Canterbury. Canterbury farmers who irrigate represent 52% of the total sample of farmers from Canterbury.

Table 1. Irrigation management practices scenarios[6]

Management practice	Description
Typical management practice (TMP)	Fixed frequency applying a fixed quantity of water each rotation.
Good management practice (GMP)	Trigger irrigation based on water available for use by plants held in the soil. Also referred to as plant-available water (PAW).
Best management practice (BMP)	Trigger irrigation based on PAW and 72-hour weather forecast. PAW trigger values in October, November and March differ from those in December, January and February.

According to survey results, just under 90% of Canterbury respondents whose primary enterprise is dairy irrigate (Figure 1). Among dairy respondents who irrigate, 95% use travelling irrigators such as pivots, 45% use manual move systems such as K-Lines and sprinklers, and 22% use fixed systems (Figure 2). Most have more than one type of irrigation system.

The majority of dairy respondents who irrigate use soil moisture sensors to help them decide when to irrigate (61%) (Figure 3), with 38% only using soil moisture sensors. The remaining 23% use soil moisture sensors in combination with other approaches. Other commonly used measures to determine when to irrigate are more subjective and include when plants look like they need it (36%) and when soil is dry (29%). A smaller proportion of respondents (16% each) use a water budget approach or a commercial irrigation scheduling service. About 13% of respondents irrigate based on when water is delivered by a scheme.

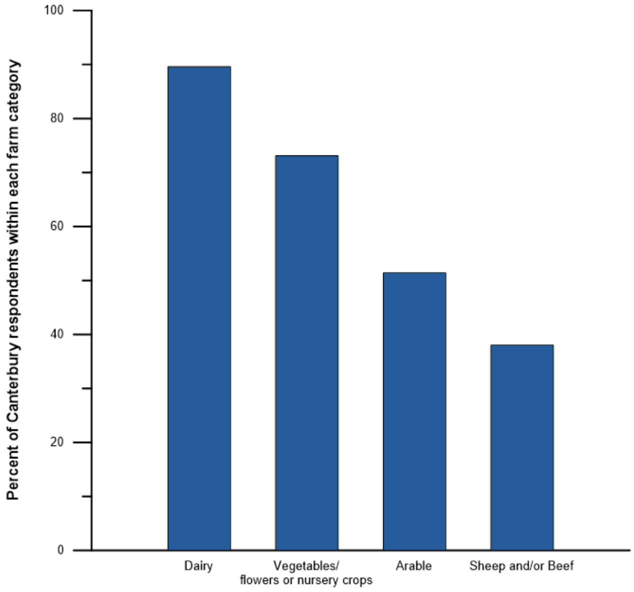

Figure 1. Proportion of Canterbury respondents with water irrigation systems (does not include effluent irrigation). Data source: 2017 Survey of Rural Decision Makers © Manaaki Whenua – Landcare Research.

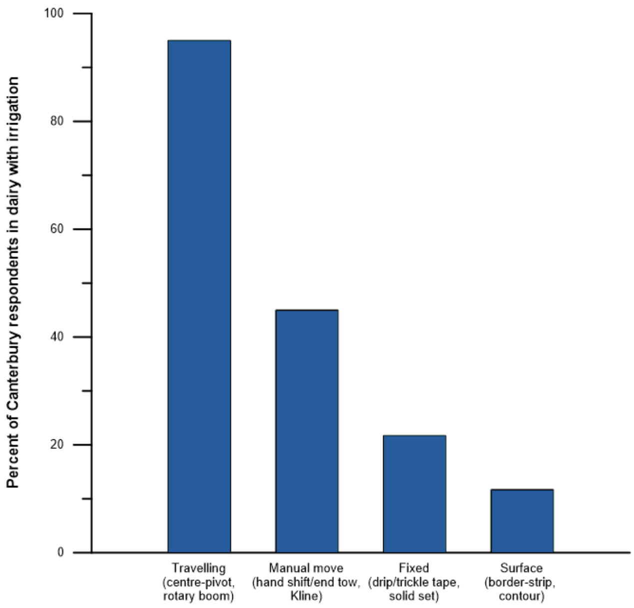

Figure 2. Types of irrigation systems in use on Canterbury dairy farms. Note: respondents could choose more than one type of irrigation system. Data source: 2017 Survey of Rural Decision Makers © Manaaki Whenua – Landcare Research.

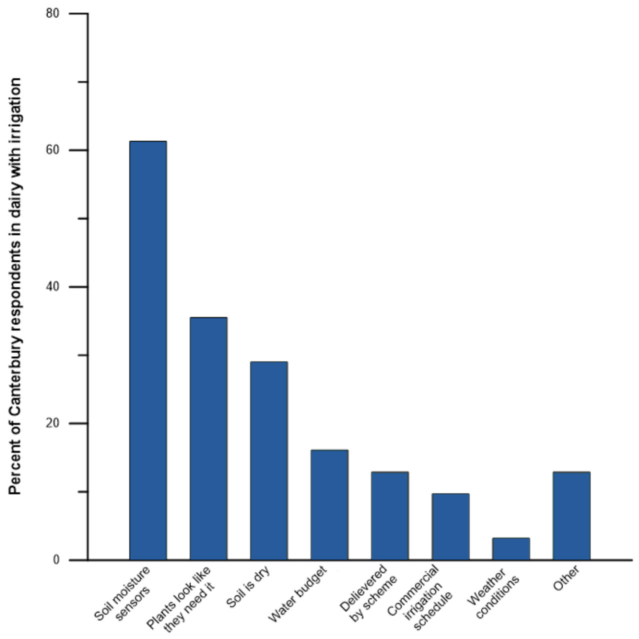

Figure 3: Timing (or trigger) for irrigation used by Canterbury respondents with irrigation systems. Note: a farm may use more than one type of trigger to determine when to irrigate. Data source: 2017 Survey of Rural Decision Makers © Manaaki Whenua – Landcare Research.

COMPARING IRRIGATION MANAGEMENT PRACTICES

Three types of irrigation seasons – driest ('dry'), median, and wettest ('wet') – are compared based on typical, good, and best management practice scenarios (see Box 2 for modelling details).

IRRIGATION, DRAINAGE AND PLANT-AVAILABLE SOIL WATER (PAW)

Drainage indicates the amount of water lost through the soil profile. Figure 4 shows rainfall, irrigation and drainage (separated into rainfall drainage and irrigation drainage) for the dry, median and wet irrigation seasons. Rainfall drainage is defined as water lost from the root zone that would have occurred naturally with no irrigation. Irrigation drainage is the additional drainage occurring as a result of irrigation.

Since TMP followed a fixed routine, the amount of irrigation applied did not change across seasons (600 mm). During the driest season, GMP and BMP resulted in slightly more irrigation than TMP (approximately 650 mm). However, irrigation in GMP and BMP scenarios reduced to approximately 400 mm in the median season and to about 200 mm in a wet season. As the amount of irrigation varied between practices, so did the amount of irrigation drainage generated. BMP and GMP generated significantly less drainage than TMP across all seasons.

PAW provides information on soil moisture content and is an important metric for determining pasture growth. Figure 5 illustrates the proportion of time during the irrigation season when soil moisture is at, below or above certain thresholds, namely 50 and 100% PAW. This figure demonstrates the proportion of time the soil moisture is not limiting pasture production (i.e. when it is between 50 and 100% PAW).[7] Generally, even during the driest and wettest seasons, GMP and BMP held soil moisture between 50 and 100% PAW more of the time than TMP. TMP, despite a large irrigation application during wet and median seasons, did not hold the soil moisture in this range as often. BMP performed consistently better than GMP in maintaining soil moisture between 50 and 100% PAW, despite minimal differences in irrigation applied (see Figure 4).

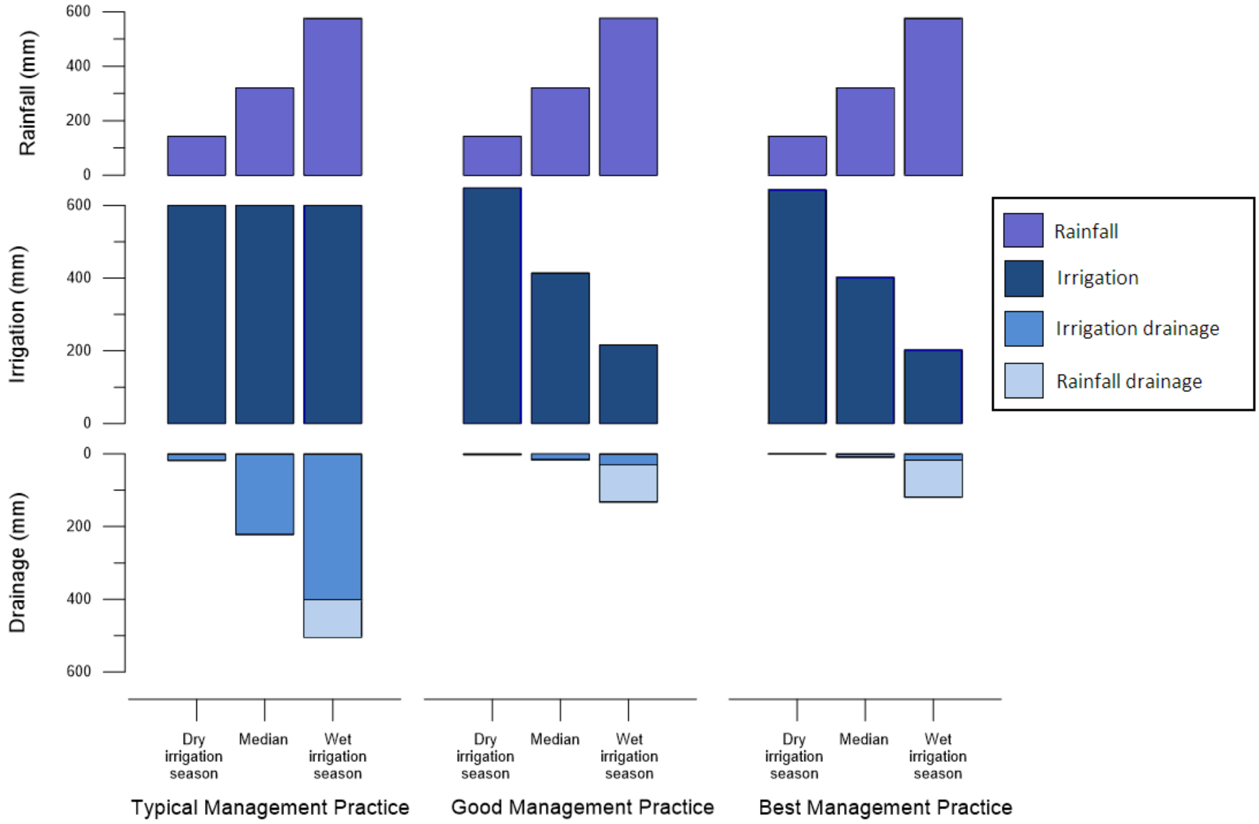

Figure 4. Total rainfall (mm), total irrigation (mm), and total drainage (mm) under TMP, GMP and BMP. Dry, wet and median seasons are based on the amount of rainfall received during the irrigation season. See Box 2 for modelling details.

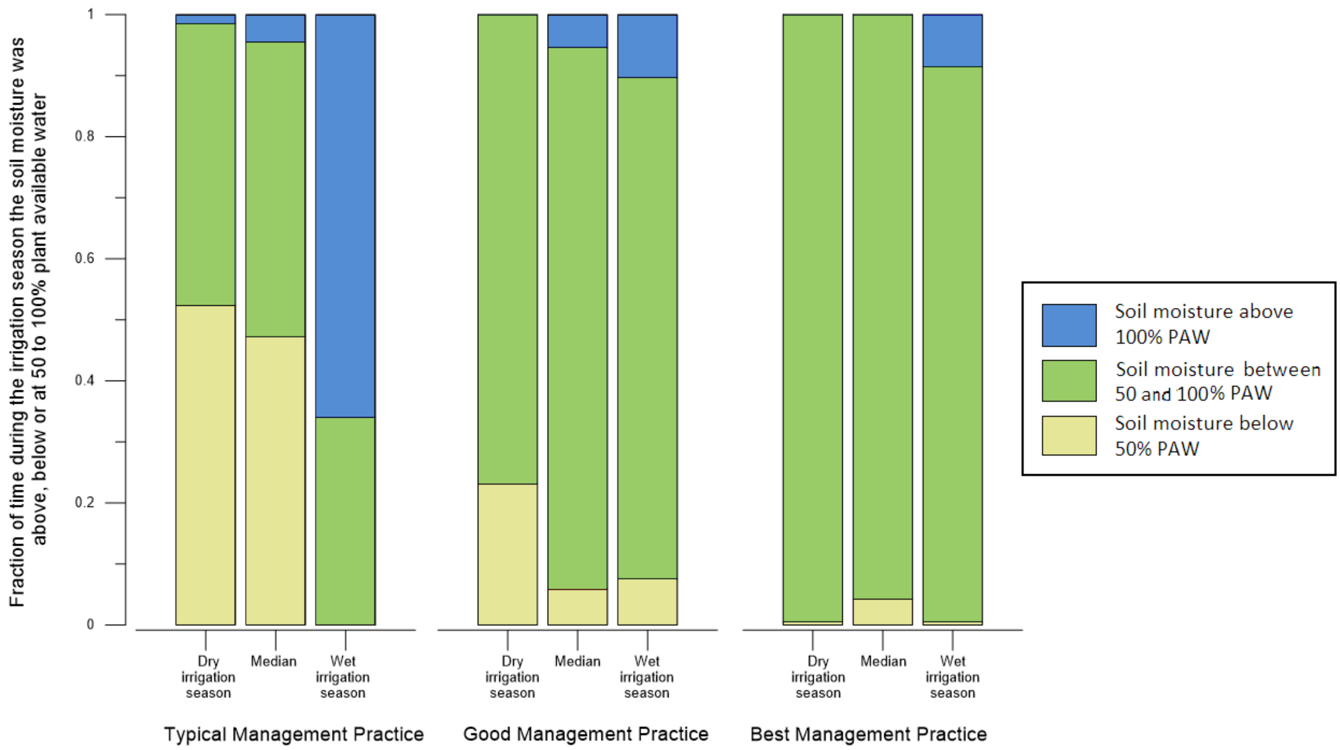

Figure 5. Soil moisture under TMP, GMP and BMP.

COST AND VALUE IMPLICATIONS

The relative economic performance of the different scenarios can be seen in Figure 6, where the 'total value (value of pasture minus direct economic costs) varies between irrigation management and season.

Direct costs are consistent across TMP scenarios; however, the value of pasture grown decreases in wetter irrigation seasons, indicating the negative impact of overwatering.

This is likely to be especially problematic for farms with heavy soils, which are particularly sensitive to overwatering in the autumn shoulder of the irrigation season with an increased risk of saturated soils and pugging damage.

GMP and BMP practices were sensitive to variability in seasonal conditions, altering irrigation applications as rainfall varied (e.g. a wetter irrigation season received fewer irrigation events than a median or dry season). Therefore, direct costs were reduced due to fewer irrigation events.

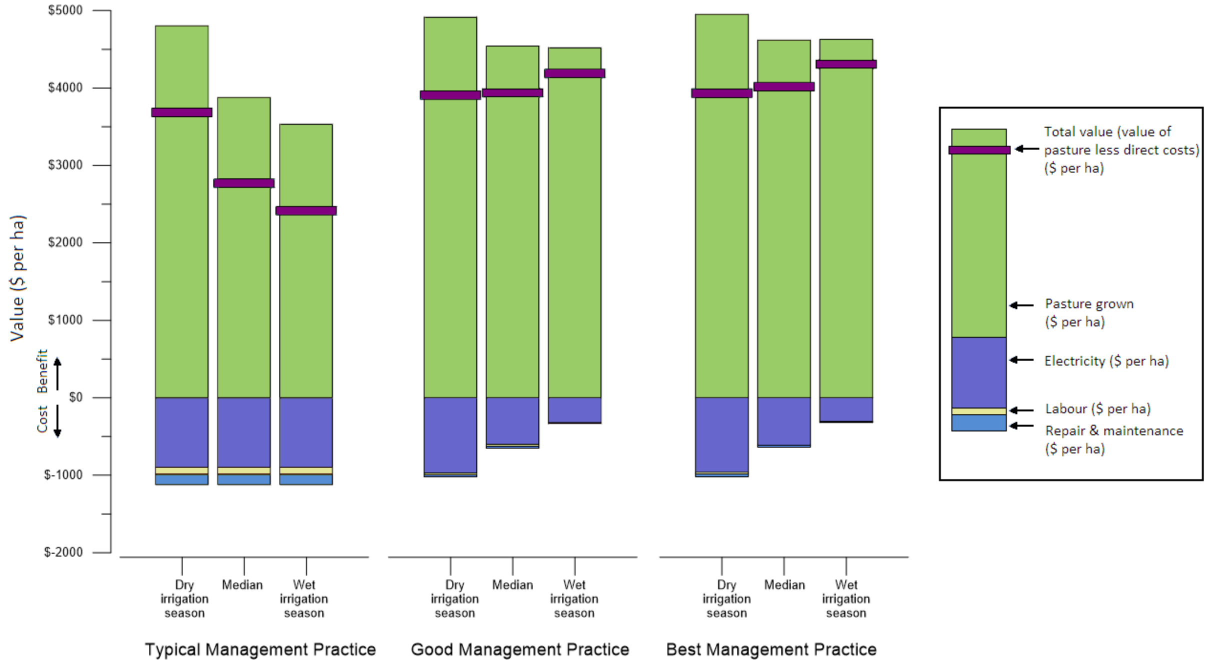

Figure 6. Economic costs and pasture value under TMP, GMP and BMP.

IMPROVING ECONOMIC AND ENVIRONMENTAL IRRIGATION BENEFITS

The ability to control soil moisture, particularly to stop soil getting too wet from rainfall, has a positive effect on pasture production. This is seen by greater dry season pasture growth for GMP and BMP than in the median and wet seasons (which showed minimal difference). However, this positive economic effect of more pasture growth in the dry season was offset by higher costs. Higher costs are the result of higher electricity costs from an increase in volume of irrigation water used and more repairs, as well as maintenance and labour costs from more irrigation events. Thus, the wet irrigation seasons performed better in terms of total (net) value than the dry seasons for both BMP and GMP, the opposite to what happens under TMP.

There are economic and environmental benefits (based on water use and drainage) in moving from roster-based irrigation approaches (TMP) to using soil moisture (GMP and BMP). This is starting to happen, as shown by the fact that 61% of irrigated Canterbury dairy farmers who responded to the 2017 SRDM used soil moisture sensors to schedule irrigation.

POLICY IMPLICATIONS

We have shown that using soil moisture to schedule irrigation events is more environmentally sustainable and economically beneficial than applying a fixed amount of water each irrigation event. Understanding the costs and benefits of different management practices is crucial in assessing the impact of policies relating to irrigation and water use. The challenge is how to move the remaining farmers to use soil moisture to trigger irrigation.

Nuances should be recognised, given that some farmers may not have irrigation flexibility. To account for contextual constraints, the information generated through modelling should be overlaid with information on irrigation infrastructure, as there will be some who, even with soil moisture sensors, are locked into a particular practice due to their own farm infrastructure or access to water (e.g. supply infrastructure). Some of these nuances are beyond the scenario-based modelling we have undertaken, but they do highlight the issues encountered when enforcing blanket 'practice' rules, given the inability of all farmers to conform to those rules.

WHAT NEXT?

Additional analysis is needed to test the key modelling assumptions (see Box 2) and to better understand the differences between GMP and BMP. This research work is ongoing, and consideration needs to be given to what scenarios are most beneficial to test and how this information can be translated and provided to key stakeholders such as farmers, policymakers and industry.

Box 2. Methodological approach

We ran a hydrology model[8] over 18 irrigation seasons (1999/2000 to 2016/17) to simulate soil moisture and irrigation under typical, good and best management practices scenarios for the driest ('dry'), median, and wettest ('wet') rainfall irrigation seasons. Given the wide range of irrigation management practice across New Zealand,[5,9] irrigation practices were categorised under three major groups based on the method used to schedule irrigation, as described in Table 1. The model represents a hypothetical 223 hectare North Canterbury farm,[10] and all hectares are assumed to be irrigated. Historical weather data recorded at a weather station in Rangiora were used to set rainfall and potential evaporation in the model. The rainfall modelled was approximately 143 mm in the dry season, 320 mm in the median season, and 580 mm in the wet season.

We then ran an economic model to estimate the costs and pasture values under each irrigation management practice.[11] The economic costs include direct 'cash' costs (e.g. pumping, maintenance and labour)[12] and indirect 'pasture impact' costs (e.g. pasture growth, as affected by soil moisture, pasture wastage and pugging).[13] Only costs that are expected to change because of changing scheduling decisions are included. As such, consent and compliance costs are not included. The reduction in pasture growth as a result of irrigation should be interpreted as a comparison with the base scenario (see Table 2).[14]

Table 2. Monthly base pasture growth rates and economic value of pasture[15,16]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kg DM/ha/day	80	82	75	55	32	17	15	28	48	79	85	90
$ per kg DM	0.14	0.14	0.26	0.26	0.45	0.45	0.41	0.41	0.41	0.31	0.31	0.14

The pasture impact and direct cash costs per hectare are combined to provide a 'total value', which is the value of pasture minus the direct economic costs. It should be noted this is not equivalent to gross income or operating profit, as it does not consider what the pasture is used for (i.e. including milk price); it is solely a value on the pasture grown, based on the Forage Value Index[16] and operating costs associated with irrigation (no other farm expenses are included).

The modelling results are based on a range of assumptions. In particular:

- one soil type with medium water-holding capacity (up to 90 mm water able to be stored within the top 600 mm of soil (root zone); i.e. PAW equals 90 mm
- perfect irrigation water supply (100% supply reliability, even during the dry years)
- weather forecasting is 100% accurate
- average farm inputs and costs, including base pasture production
- dairy land use only (milking platform only, with cows wintered off for June and most of July), standard ryegrass and white clover pasture mix
- no nutrient limits to pasture growth
- effluent irrigation and variable rate irrigation are not considered.

The scenarios described here do not capture behaviour such as overwatering ahead of possible supply restrictions, or pasture response to prolonged periods of soil moisture stress due to limited water. They also assume that when a farmer wants water, such water is available and there is no associated lag time, which can be the reality for some irrigation schemes where there is a delay between ordering and receiving water. Some of these assumptions are explored further in Srinivasan et al. (in prep.).

Note: Srinivasan et al. (in prep.) is the journal article that explains in detail the hydrology model and methods used in this brief.

Table 3. Details of management practices scenarios

	Typical management practice (TMP)	Good management practice (GMP)	Best management practice (BMP)
Definition	Fixed frequency applying a fixed amount each rotation.	Start irrigation at 50% plant-available water (PAW) and stop at 90% PAW.	Use of weather forecast to trigger irrigations with varying trigger points.
Rotation length	• Every 8 days in Oct & Apr • Every 5 days in Nov & Mar • Every 3 days in Dec, Jan & Feb	No	No
Irrigation trigger: start	Not considered	50% PAW	• 55% PAW in Oct, Nov, Mar & Apr • 60% PAW in Dec, Jan & Feb
Irrigation trigger: end	Not considered	90% PAW	• 80% PAW in Oct, Nov, Mar & Apr • 90% PAW in Dec, Jan & Feb
Irrigation per event (mm)	• 15 mm in Oct, Nov, Mar & Apr • 10 mm in Dec, Jan & Feb	36 mm	• 22.5 mm in Oct, Nov, Mar & Apr • 27 mm in Dec, Jan & Feb
Weather forecast used	No	No	Yes (72-hour forecast)
Sources and comments	There is no comprehensive survey of current irrigation practices that covers all the inputs to the model. As such, TMP is based on the results of the SRDM and supplemented by additional inputs based on expert opinion. TMP uses a rule of thumb that 5 mm of water is lost every day as evaporation and should be replaced to maintain soil moisture conditions.	Spray irrigation was set at a 50% trigger point for Overseer modelling in the Canterbury Land and Water Plan; a 90% stop point was used to simulate the requirement to 'minimise risk of leaching and runoff', as per Schedule 28, GMP Modelling Rules.[3]	One definition for BMP has arisen from the Plan Change 5 hearings process (Variation 5 to the Canterbury Land and Water Plan). In this process, an 80% irrigation application efficiency was suggested by submitters to be GMP, while 100% irrigation application efficiency was considered to be BMP.[17] The irrigation triggers used are designed to ensure soils remain below saturation from irrigation.[8,18]

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[2] LIC & DairyNZ. (2018) *New Zealand Dairy Statistics 2017-18.* Hamilton, New Zealand. https://www.dairynz.co.nz/media/5790451/nz-dairy-statistics-2017-18.pdf

[3] ECan. (2019) Schedule 28 Good Management Practice modelling rules, *Land and Water Regional Plan* (Revision: 16-Sep-2019) https://eplan.ecan.govt.nz/eplan/#

[4] MGM Group (Matrix of Good Management Group). (2015) *Industry-agreed Good Management Practices Relating to Water Quality.* Version 2. https://www.ecan.govt.nz/document/download?uri=2378592

[5] Brown, P. (2017) *Survey of Rural Decision Makers.* Manaaki Whenua – Landcare Research, Wellington, NZ. doi: 10.7931/J2736P2D.

[6] It is worth noting that there is no explicit, consistent definition of these practice groupings. We defined each scenario based on available data sources and consultation with experts. Table 3 describes each scenario in more detail and describes the sources of the information.

[7] Though pasture wastage and pugging have different thresholds.

[8] Srinivasan, M.S., Measures, R., Muller, C., Neal, M., Rajanayaka, C., Shankar, U., Elley, G. (in preparation). Comparing the environmental footprints of just-in-case, just-in-time, and justified irrigation practices using a scenario-based modelling tool, *Agricultural Water Management.*

[9] EECA & IrrigationNZ. (2014) *Irrigation Energy Efficiency Evaluation Pilot Project Summary Report*. Energy Efficiency and Conservation Authority, Business and Irrigation New Zealand, Christchurch, New Zealand. https://www.irrigationnz.co.nz/KnowledgeResources/Attachment?Action=Download&Attachment_id=73

[10] Averages for Marlborough–Canterbury farms used from DairyNZ Economics Group (2019). *DairyNZ Economic Survey 2017-18.* DairyNZ, Hamilton, New Zealand. https://www.dairynz.co.nz/media/5791415/dairynz-economic-survey-2017-18.pdf

[11] Muller, C., Neal, M., Srinivasan, M.S., & Measures, R. (2018) Economic implications of altering irrigation scheduling, *Australasian Dairy Science Symposium,* Palmerston North, New Zealand. 22 November 2018.

[12] The direct economic costs were primarily sourced from DairyBase, and the irrigation electricity costs (for pumping and supply) were measured by volume ($0.15/m^3), while maintenance and labour were based on a daily rate for each day irrigation was used ($138 and $93, respectively, per day). While the electricity costs appear high, these account for both electricity costs and costs labelled as 'irrigation other' in the farm working expenses in DairyBase.

[13] Indirect costs considered in this study are reductions in pasture growth and wastage due to soil moisture levels, and reduction in pasture growth from pugging when soils are wet. Pasture wastage refers to the change in pasture utilisation that is affected by soil moisture, while pugging refers to trampled, wet soil affecting pasture growth.

[14] For detail on all these relationships, see Muller et al. (2018). The base pasture growth rates (PGR) were based on *DairyNZ Facts & Figures* from the Lincoln University dairy farm location (DairyNZ 2017). The economic value of pasture is derived from the Forage Value Index from the Upper South Island (Ludemann 2019).

[15] DairyNZ. (2017) *Facts and Figures*. 2nd edition. DairyNZ, Hamilton, New Zealand. Accessed 10 June 2018, https://www.dairynz.co.nz/media/5789569/facts_and_figures_web

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[18] K.C., B., Mohssen, M., Chau, H., Curtis, A., Cuenca, R., Bright, J., Srinivasan, M.S., Hu, W., Cameron, K. (2018) Impact of rotational grazing systems on the pasture crop coefficient for irrigation scheduling. *Irrigation and Drainage*. doi: 10.1002/ird.2210