An Investigation of the Potential Benefits of Hydroclimate Forecasts for Irrigators in Northern Victoria

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EXTENDED ABSTRACT

Australia is not only the driest inhabited continent, but it also has low and highly variable runoff. Furthermore, apart from the northernmost regions of the country, the water in most Australian rivers is currently either fully or, in some cases, over committed. As a consequence the annual availability of water for irrigation is both limited and uncertain. The recent extended drought throughout much of Australia has resulted in below average irrigation allocations in many areas. This has prompted a renewed interest in the probabilistic forecasting of these allocations prior to the opening of the irrigation season, such as is currently provided by Goulburn-Murray Water. The question arises however as to the practical usefulness of these forecasts for farmers.

This paper investigates the potential benefits of perfect foreknowledge of hydroclimatic variables (water allocations, rainfall and evaporation) for sorghum, wheat and tomatoes, and for dairying, in the Goulburn irrigation region of northern Victoria, Australia. The operation of individual farms was modelled at a time step of at least several weeks. For cropping activities the options considered were to vary the area planted, deficit irrigate, and trade water on the temporary market; and for dairy farming they were to deficit irrigate the pasture, vary the amount of supplement fed, and trade water on the temporary market. The scenario returning the highest gross margin was then determined. The benefits of having perfect knowledge of the hydroclimatic data for the forthcoming season were shown to depend upon the price of water on the temporary water market, the ratio of the maximum irrigated area to the water right, and the climatic season. For cropping/horticultural activities they also depend on the length of the period of the agricultural activity that falls within the irrigation season, the sensitivity of the crop to water deficits, and the economic margins of the activity. For dairying the stocking density and the cost of supplements will have an impact on how beneficial hydroclimatic forecasts are. As anticipated, the results obtained showed that the primary impact of hydroclimatic factors on the optimum scenario for an irrigator in a water-trading environment is on the irrigator's water trading decisions, which are short-term decisions, rather than on their longer-term planning decisions. If there were no limits to the volume of water being traded, and the water prices were low to average (<$100/ML), then an irrigator involved in cropping/horticultural activities would almost always be advised to plant the maximum area available and fully water the crop, purchasing water as necessary. A dairy farmer would be advised to water the pasture fully, again purchasing water as necessary, and feed only the minimum supplement required.

As the price of water increases (>$100/ML), then for a cropping farmer with a small economic margin, such as is the case for sorghum, the highest returns may be obtained from planting a smaller area. If the crop has a low sensitivity to water deficit, such as is the case for wheat, then deficit irrigation may be the optimum scenario, even to the extent of deficit irrigating the crop to sell water. If there is an unlimited supply of water on the temporary water market, then the potential benefits of hydroclimate forecasts for farmers growing crops with a high economic margin which are very sensitive to water deficit, such as tomatoes for the fresh market, are very limited. For dairy farmers the optimum scenario will involve substituting supplement for pasture only when the price of water is greater than that of the supplement. The total metabolisable energy intake by the cattle should always be such that near maximum volumes of milk are produced however.

The primary conclusion of this study is therefore that hydroclimatic forecasts have the potential to be of benefit to some irrigators, but probably only if they can also be used to forecast the price of water on the temporary water market.

1. INTRODUCTION

In Australia irrigation water is only made available within a fixed time period, the irrigation season. The availability of irrigation water in the forthcoming irrigation season is always both limited and uncertain. Where irrigation water is obtained from a regulated supply the allocations are made as a percentage of a fixed volume of water that a farmer has an entitlement to. In northern Victoria, where the irrigation season generally extends from the 15th of August through to the 15th of May, irrigation allocations of up to 200% of a farmer's water rights may be made available. The first 100% is intended to be a long term secure entitlement. The second 100% is made available only after a further 100% of water rights have been set aside for the following year. Water allocations are therefore dependent upon climatic conditions in both the previous and the current season. Any irrigation water that a farmer does not use in a given season is not able to be carried forward for their use in the following season.

For the Goulburn system under 93/94 levels of development, 100% of water rights or greater would have been available by the end of the irrigation season for 108 out of the past 112 years, and 200% of water rights in 47 of the years. The average allocation at the end of the season was 158% of water right, and the median was 178%. As a result of the high average allocations, many irrigators, particularly dairy farmers, have developed their farms in the expectation that some sales water will always be available. They are therefore highly vulnerable to low water allocations.

Temporary water trading (for periods of less than a year only) was first introduced in the Goulburn-Murray Irrigation Scheme in the 1987/88 irrigation season. Temporary water trading is limited to 130% of a farmer's water right however.

The recent drought has prompted interest in the probabilistic forecasting of irrigation allocations prior to the start of the irrigation season, as a tool to assist irrigators in planning their farming operations. It has been shown that such forecasts have the potential to be of benefit to risk averse cotton growers in the Namoi and Border Rivers catchments (Abawi et al., 2001; Letcher et al., 2004; Ritchie et al., 2004) and to risk averse mixed farmers in the Murrumbidgee catchment (Khan et al., 2004). The first three of these studies did not allow for water trading, and none of them specifically considered the deficit irrigation of crops or the feeding of supplements to dairy cattle as an alternative to the irrigation of pastures.

The aim of this paper is to investigate the potential benefits of forecasts of hydroclimate variables on the watering decisions of an individual farmer in a temporary water trading environment. This was undertaken by modelling individual farms in the Shepparton irrigation area of northern Victoria, and determining the choices that would lead to the maximisation of the gross margin if the rainfall, evaporation and irrigation allocations were known. The sensitivity of these decisions to the price of water on the temporary water market was then determined.

2. MODELLING OF INDIVIDUAL FARMS

Examples of an annual summer crop (sorghum), winter crop (wheat) and horticultural crop (tomatoes for the fresh market), and a dairy farm, were considered. For each of these the aim of the model was to maximise the gross margin, calculated as: [return from yield + return from selling water on the temporary water market – costs associated with agricultural activity – cost of buying water]. Significantly different physical models were required to relate water applied to yield obtained for cropping/horticultural and dairying activities.

For cropping/horticultural farms the options considered were to vary the area of crop planted and the amount of water applied. For dairy farms the options were to vary the amount of supplement that was fed to the cattle and the amount of water applied to the pasture. For both cropping and dairying, water trading on the temporary water market was considered.

Because these models are intended to be used in conjunction with seasonal forecasts of hydroclimatic data the time-step used for the cropping/horticultural model was the growth stages of the crops, and for dairying it was seasonal. In all cases the historical rainfall and evaporation data were obtained from the Department of Natural Resources as part of the PRIDE data set for the period 1890-91 to 2002-03. The annual water allocations for each of these years were obtained by running the Goulburn Simulation Model (Department of Sustainability & Environment).

The benefits of hydroclimate forecasts should be greatest for farmers who have insufficient irrigation water available. For all the farms considered here the ratio of water entitlement to irrigable land that was used was therefore low. Constraints on the volume of irrigation water that can be supplied due to the physical capacity of the system were not included. Unless otherwise specified it was assumed that there was no limit on the volume of water available for purchase or able to be sold on the temporary market. The price of water on the temporary water market was varied from $0 through to the price at which a farmer would optimise their profit by selling their entire saleable allocation.

3. CROPPING/HORTICULTURAL MODELS

3.1. Model Development

The dated crop-water function of Jensen (1968) was used to obtain the relationship between crop yield and water applied. This gives the ratio of the actual yield obtained under a situation of water deficit to the potential yield, as a function of the ratio of actual evapotranspiration to the evapotranspiration that would have resulted from the maximum crop yield. It was assumed that the latter ratio can be approximated by the ratio of water supplied to water demanded. The pan evaporation equation of Doorenbos and Pruitt (1992) was used to determine the water demand corresponding to the maximum crop yield.

The equation of Kipkorir and Raes (2002) was used to relate Jensen's sensitivity index to the more readily available yield response factor of Doorenbos and Kassam (1979). If the opening or closing of the irrigation season cut across a growth stage then the method of Tsakiris (1982) was used to determine the sensitivity indices for the two sub-periods.

The optimisation of the gross margin was done by the simple iterative process of incrementally increasing the area planted from the minimum up to the maximum, and then for each area increasing the irrigation water applied during each growth stage from zero up to that required to obtain the maximum yield, again in fixed increments. The gross margins were compared to determine the scenario giving the largest value. It was assumed here that the quality of the crop was not affected by any water deficit, but the validity of this assumption will need to be reviewed.

3.2. Data used

For wheat and sorghum the maximum irrigated farm area was taken to be 80ha, and the water entitlement to be 100ML. For tomatoes the maximum irrigable area and water entitlement that were used were 50ha and 80ML respectively. The potential yield and production costs and returns were taken from Queensland Department of Primary Industry notes for irrigated cropping on the Darling Downs. Fixed commodity prices were used regardless of the climatic season. For wheat the planting date, crop coefficients and lengths of growth stages were based on PRIDE data. The crop yield response factors were obtained from the Food and Agriculture Organization (FAO). The planting date and total growing period for sorghum and tomatoes were based on information from the Victorian Department of Primary Industries. The crop coefficients, crop yield response factors, and length of growth stages were based on FAO data.

3.3. Results

For **wheat**, when the price of water on the temporary water market was low, the optimum gross margin was obtained by planting the maximum amount of irrigable land and fully watering it, buying water where necessary. The production costs for wheat were quite low ($340/ha), and the returns per tonne were reasonably good ($267/t). Therefore, as the price of water increased above about $200/ML, the optimum scenario generally involved deficit irrigating the crop, sometimes to levels that resulted in less than half of the maximum yield being attained, while still planting the entire area. The optimum water trading scenario changed from purchasing the water required to fully irrigate the crop through to purchasing less water and finally to selling some of the irrigation allocation rather than applying it to the crop. Depending upon the seasonal evaporation, rainfall and irrigation allocation, as the price of water increased to between about $400 and $1200/ML the optimum scenario changed to planting no crop at all and selling the entire irrigation allocation saleable. Reducing the amount of water available for trade to 30ML had little impact on the optimum planting scenario.

For **sorghum**, the sensitivity of the optimum area planted, optimum yield obtained, and optimum volume of water purchased, to water price are shown in Figure 1. As for wheat, when the price of water on the temporary water market was low the optimum scenario was to plant the maximum amount of irrigable land and fully water it, buying water as required. Sorghum had higher production costs ($560/ha) than wheat, and lower returns per tonne ($188/t), although a higher yield was obtained. In the years when the allocation provided less water than the crop demanded, at higher water prices the optimum scenario therefore generally involved planting a lesser area but fully watering the crop. At even higher water prices the optimum scenario at times involved buying less water to very slightly deficit irrigate. The water price at which the decision was made to sell the entire saleable allocation varied between about $140 and

$340/ML depending upon hydroclimatic conditions. If there was a limit on the amount of water available for purchase the optimum scenario involved a combination of reducing the planting area and some deficit irrigation. However there were no occasions where the optimum scenario involved deficit irrigation in order to sell water.

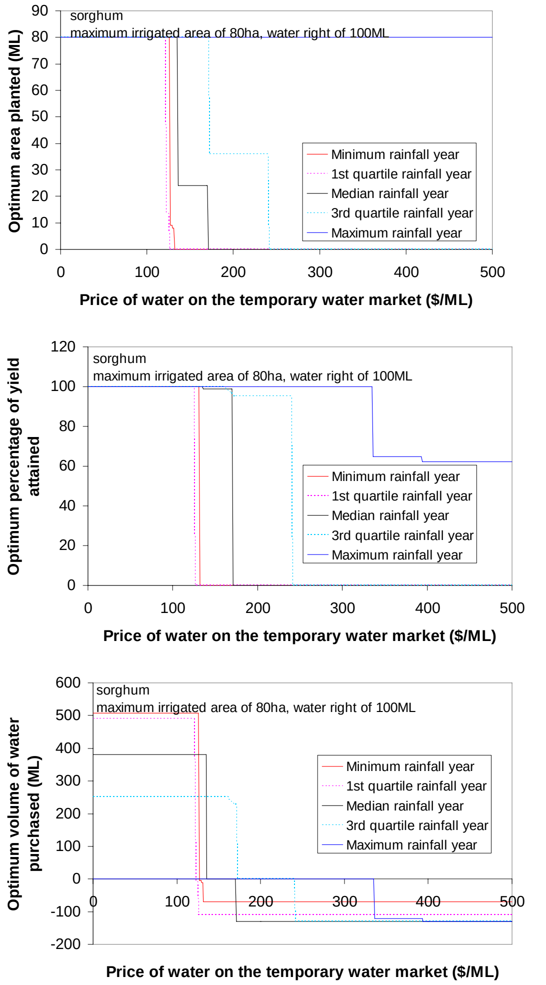

Figure 1. Sensitivity of optimum area planted, optimum yield obtained and optimum volume of water purchased to water price for sorghum. Negative water purchases indicate the sale of water.

For **tomatoes**, the optimum scenario involved planting the maximum amount of irrigable land and fully watering it, buying water where necessary. Tomatoes for the fresh market have extremely high production costs ($8,730/ha plus $5.88/carton picked), very high returns, and are very sensitive to water deficit. It was therefore only when the price of water on the temporary water market reached unrealistic levels, around $1000/ML, that the optimum scenario changed to selling the entire water allocation saleable and planting no crop. If there was a limit on the amount of water able to be purchased the optimum scenario was to plant a reduced area and fully irrigate the crop.

4. DAIRYING MODEL

4.1. Model Development

There was no model available that gave the milk yield in relation to a specified application of water to the pasture, or that could be readily modified to optimise the gross margin as a function of water applied to the pasture. It was therefore necessary to build an appropriate model. The primary steps involved, and the interactions between them, are summarised in Figure 2. In developing the model it was assumed that the entire milking area was planted with mature irrigated pasture, that there was no non-milking stock grazing the milking area, and that no forage or hay was made from the milking area. All calculations were for the lactation period only. A common calving date was used.

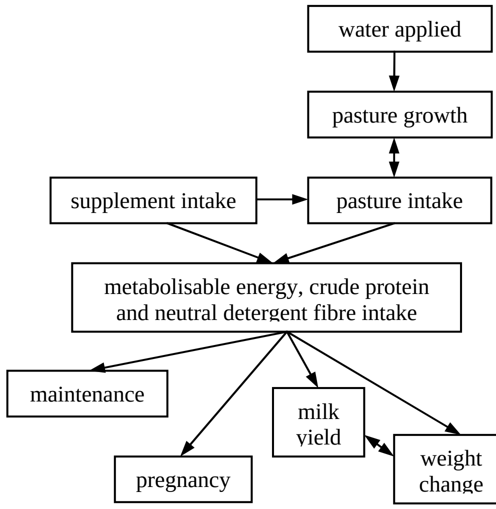

Figure 2. Interactions between primary factors in determining milk yield in dairy cows at a given stage of lactation

The field measurements of pasture growth and pasture intake by cattle that are available are limited in terms of volumes of water applied and pasture and stock management scenarios. It was therefore decided to use results from the DairyMod program (Johnson, 1998-2005) to model the pasture growth and intake. DairyMod employs a detailed pasture and grazing model developed for Australian grazing conditions. It allows for a variety of soil types, pasture species, and pasture and stock management options.

Using the DairyMod program it was found that, for a specific stocking rate and level of supplement fed, there is a reasonably linear relationship between pasture intake and water applied in spring, summer and autumn. This plateaus at different levels for each season. In winter there is no apparent relationship between pasture intake and water applied, so the average value of pasture intake was used. This is of little significance here because in northern Victoria there is no irrigation in winter.

As DairyMod does not allow for the substitution effect all DairyMod runs used were for the case of no substitute being fed. The pasture intake obtained was then modified for the substitution effect using the relationships developed by Stockdale (2000). To ensure that the combined feed intake was not greater than the amount that a cow would physically consume, the equation developed by Freer et al. (2003) for the maximum potential dry matter intake was then applied.

DairyMod also outputs the metabolisable energy (ME) intake from pasture. There is a fairly linear relationship between this and the volume of water applied. To determine the ME of the pasture intake, the water applied corresponding to the actual pasture intake after substitution has been accounted for, was determined from the DairyMod relationship between pasture intake and water applied. This volume of water was then used to determine the corresponding ME intake from pasture.

DairyMod does not give crude protein and neutral detergent fibre values for the pasture so average values obtained from the pasture databases for the region were used. The protein and fibre requirements of the dairy cows were taken from tables of recommended values.

ME requirements for maintenance, activity and pregnancy were calculated using the appropriate equations from the Australian Agricultural Council (Ruminants Subcommittee, 1990), Heard et al. (2004) and Freer et al. (2003) respectively.

The equation developed by Woods et al. (2003) was used to estimate the annual milk yield from the ME intake. The equation for the maximum daily potential milk yield given in Freer et al. (2003) was then used to determine the fraction of milk which would, under ideal conditions, be produced in a particular season. Because underfeeding a cow in early lactation reduces milk production for the whole lactation period, the milk production in later seasons was not increased if the ME intake was later increased. The ME required to produce the milk was determined from the equation given in the Australian Agricultural Council (Ruminants Subcommittee, 1990) for an assumed fat, protein and lactose concentration.

The weight change was also calculated using the relevant equation given in the Australian Agricultural Council (Ruminants Subcommittee, 1990). The net ME available was determined from the ME intake less requirements for maintenance, pregnancy and lactation. The body condition score of the cow was calculated using the equation of Johnson (1998-2005). The maximum acceptable weight loss was set by the user.

When determining the scenario returning the maximum gross margin two different supplements were allowed for. The feeding requirements and expenses associated with any non-milking stock were ignored. It was assumed that there were no additional costs in feeding supplement beyond the cost of the supplement itself.

The optimisation was undertaken by the simple iterative process of incrementally increasing in turn the water applied to the pasture, the forage fed to stock and the concentrate fed to stock. The gross margins obtained for the iterations were compared to determine the scenario giving the largest value.

4.2. Data used

The dairy farm considered was comprised of 12.5ha of annual pasture and 37.5ha of perennial pasture. In DairyMod this was divided into 20 paddocks and a time based rotation, with a target rotation length of nineteen days, was used. The pasture was grazed by 150 cows, which were assumed to have an average maximum milk production of 25L/cow/day. The supplements fed were hay and a wheat concentrate. The maximum amount of either supplement that could be fed was limited to 6kg/cow/day. The price of the supplement was constant regardless of the climatic season. A water entitlement of 90ML was used.

4.3. Results

The optimum gross margin was found to correspond to maximum or near maximum milk production, regardless of the price of water on the temporary water market. The sensitivity of the optimum volume of irrigation water applied, the optimum volume of irrigation water purchased, and the optimum amount of supplement fed, to the market price of water are shown in Figure 3. It should be noted that the total volume of water applied is very low. This is due in part to the assumption that the pasture levels at the beginning of the season were extremely high, and therefore no irrigation was required for some time, and in part to the fact that the autumn irrigation of the annual pasture was not accounted for because this watering does not contribute to milk production.

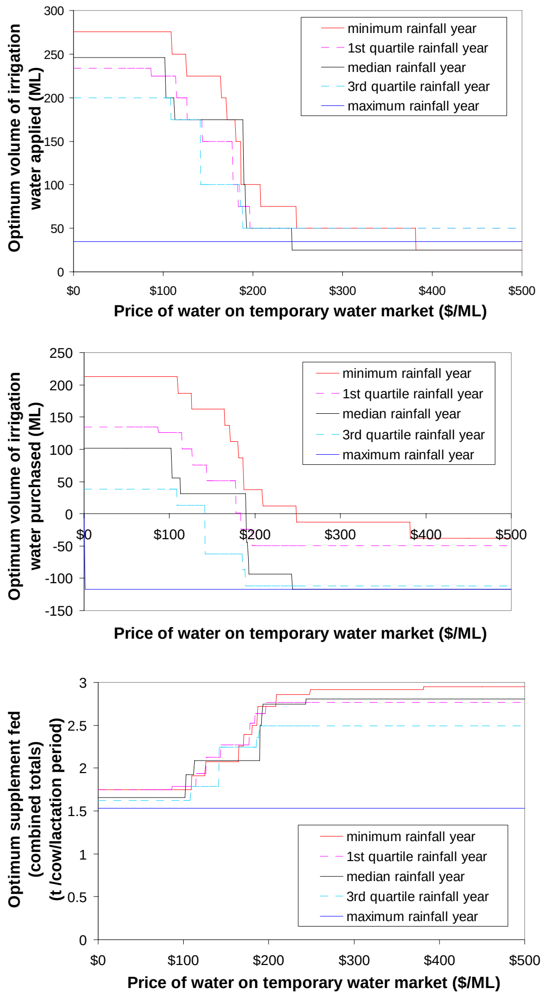

Figure 3. Sensitivity of the optimum volume of irrigation water applied, the optimum volume of irrigation water purchased, and the optimum amount of supplement fed, to the market price of water. Negative water purchases indicate the sale of water.

When the price of water on the temporary water market is greater than the cost of supplements, it becomes more economical for the dairy farmer to replace pasture with supplement. In this example the price of hay and wheat were taken to be $120/t and $260/t respectively. Therefore when the market price of water was less than about $120, the optimum scenario involved fully watering the pasture, purchasing water if required, and only feeding as much supplement as was required to satisfy the nutritional demands of the cows that were not met by the available pasture. When the water price increased above this, the optimum scenario changed to selling the irrigation water and increasing the amount of supplement fed to the cattle. For a given seasonal rainfall the transition price, and the optimum volume of water applied to the pasture, was found to vary slightly with the irrigation allocation, as well as with the price of the supplements fed.

5. CONCLUSIONS

The benefits of hydroclimatic forecasts can be considered both in terms of pre-season decision making, such as deciding upon the area of crop planted; and in terms of on-going decision making, such as choosing how much water to trade and how much supplement to buy. The results presented here, which were obtained assuming perfect knowledge of the forthcoming hydroclimatic conditions, show that the primary impact of climatic factors on the optimum scenario for an irrigator in a water-trading environment is on the irrigator's water trading decisions. While not changing their long-term operational decisions, such knowledge would be beneficial to farmers in their planning for the forthcoming season, especially as limitations to the availability of water and/or supplement available for purchase may adversely impact upon their ability to adapt their operation as the season unfolds.

For cropping/horticultural activities the benefits of hydroclimatic forecasts will depend upon the price of water, the length of the period of agricultural activity that falls within the irrigation season, the ratio of the maximum irrigable area to water right, the climatic season, the sensitivity of the crop to water deficits, and the economic margins of the activity. From the results obtained it can be concluded that, if there were no limits on the volumes of water being traded, and the price of water was less than $100/ML, a cropper/horticulturalist would always plant the maximum area available, purchasing water as required. At higher water prices, hydroclimatic forecasts will begin to be of benefit in planting decisions, particularly for crops such as sorghum which have fairly low financial returns and moderate sensitivity to water deficits.

For dairy farmers the benefits of hydroclimatic forecasts will depend upon the price of water, the ratio of the maximum irrigable area to water right, the climatic season, the stocking density, and the price of supplements. As the price of supplements will vary somewhat with the climatic season, it would be worthwhile determining if the hydroclimatic forecasts could be used to forecast the price of supplements. Hydroclimatic forecasts will be of greatest benefit to farmers if the water price is greater than that of supplement, for otherwise a dairy farmer would be advised to always water the pasture fully and feed as little supplement as possible.

For both cropping/horticultural activities and dairying it was found that for climate forecasts to be of greatest benefit to irrigators they must also be used to forecast the price of water on the temporary water market. In the seven years of its operation, the price of temporary water being traded on the water exchange (Watermove) in zone 1A of the Goulburn basin has varied from $8/ML to $500/ML. Seasonal averages have been under $100/ML, except for the 2002-03 season when the average reached $364/ML. If prices again reach these levels then hydroclimatic forecasts would indeed be of benefit to many irrigators in northern Victoria. In such cases a forecast of the volume of water being traded on the market would also be advantageous.

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