Implication of time step on crop irrigation requirements

Green SR

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EXECUTIVE SUMMARY

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Water use and allocation is one of the greatest pressures facing the water management system of the Hawke's Bay Regional Council (HBRC). The Council currently allocates its water resources on a weekly time step based on a Q5 (one in five) for surface water and a Q10 (one in ten) event for groundwater. They recognise there are some advantages in terms of reanalysing water allocation procedures e.g. to find sustainable solutions to help to conserve the region's precious water supplies.

Computer modelling and risk assessments are being used as tools to better define crop irrigation needs. This report highlights to both Council and irrigators, the water savings that can be accrued by using different time steps (e.g. weekly versus monthly calculations) in the water allocation process. We used our SPASMO model (Soil-Plant-Atmosphere-System-Model) to generate daily values of the crop water balance using local soil, crop and climate data. A statistical approach was used to examine variability in each of the water balance components. The study found:

- The requirements for irrigation generally decreased as the time period increased. This is because there is a disproportionately greater likelihood of receiving some rain in any given month than there is in receiving some rain in any given week.
- Weekly data, when scaled up by the number of days in a month, were more negatively skewed (i.e. the distribution has a larger tail towards the higher numbers) than the same calculation taken over the whole of a month. Thus the Q5 value for irrigation, as calculated from weekly balance data, would tend to over-estimate crop irrigation needs for the whole month.
- Calculating irrigation water requirements on a monthly basis yielded a 20% lower water allocation requirement cf. those calculations based on a weekly period that were scaled by the number of days in a month.
- In the case of pasture, the degree of overestimation appeared to be consistent across the summer months. Other crops yielded a similar over-estimation (data not reported).

The results from this study will be used to influence Council policy i.e. to decide which time step is best used in allocation of the freshwater resource for irrigation.

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INTRODUCTION

Water use and allocation is one of the greatest pressures facing the water management system of the Hawke's Bay Regional Council (HBRC). Further development of the accuracy and effectiveness of the Council's water allocation system is therefore of great importance to the local community, and the Hawke's Bay environment.

The Council currently allocates its water resources on a weekly time step. Irrigation consent holders are issued with a weekly volume and a take rate with which they have to comply. However, the data used to produce these values are derived from monthly averages. This poses questions for both Council and irrigators about the integrity of the methodology and whether inefficient irrigation scheduling strategies are being used to maximise drought proofing, especially for soils of low readily available water.

The Council recognises there are some advantages in terms of reanalysing water allocation procedures e.g. to find sustainable solutions to help to conserve the region's precious water supplies. It is much better to address these water issues before the resources are fully allocated, at which point reforms would probably require changes to existing use rights. Computer modelling and risk assessments are being used as tools to better define crop irrigation needs. This report highlights to both Council and irrigators, the water savings that can be accrued by using different time steps (e.g. weekly versus monthly calculations) in the water allocation process.

BACKGROUND

In the past HBRC has used a simple spreadsheet calculator to estimate irrigation demand for a range of crops grown in Hawke's Bay. Their procedure was based on a peak monthly (January) evapotranspiration value (ET, mm/month) and used a constant crop factor, K_C (set equal to 1.0 for pasture and 0.75 for grapes) to relate actual crop water use to the potential evaporative demand. The $Q5$ value for rainfall (one in 5 year low total, $Q5_R$, mm/month) was entered into the water balance calculation, and the corresponding crop irrigation needs (IR, mm/week) were calculated as

$$IR = (K_C \, ET - Q5_R)/4,$$

with the factor 4 being used to convert monthly totals into weekly totals. This simple water balance equation ignores the storage capacity of the soil and neglects seasonal changes in crop water use due to development of the crop's green leaf area. These past calculations were also inappropriate for scaling up to monthly or seasonal values of crop water demand.

The Council's calculation procedures have recently been upgraded, under Envirolink Project HBRC36, whereby HortResearch carried out a local calibration of the SPASMO model. SPASMO uses historical records of daily climate data combined with hydraulic properties of local soils to calculate crop's irrigation needs. The software reports monthly and annual statistics for use in the water allocation process.

SCOPE OF THIS STUDY

The task here was to compare outputs of the two calculation procedures, focussing on the difference between weekly and monthly time intervals.

MODELLING APPROACH

We have used SPASMO to generate daily values of the crop water balance using local soil, crop and climate data. Crop water use, ET_A (mm/day), is calculated using the FAO-56 crop factor approach (Allen et al. 1998):

$$ET_A = K_C\,ET_O$$

where K_C is a crop factor that reflects changes in crop characteristics (e.g. crop development) over the growing season, and ET_O (mm/day) is the reference evapotranspiration. Changes in the amount of water held in the root-zone (ΔW, mm/day) are calculated from the following soil water-balance equation:

$$\Delta W = IR + RF - ET_A - RO - DR$$

that considers the inputs (IR = irrigation, RF = rainfall) and outputs (ET_A = crop evapotranspiration, RO = run-off, and DR = drainage) of water from the root-zone soil. Plant roots extend to a depth of Z_R (mm). For the purpose of calculation, irrigation is applied whenever the root-zone soil water content (W, mm) drops below a critical stress-point value (W_{SP}, mm), that is defined by:

$$W_{SP} = W_{FC} - \Delta_T\,(W_{FC}-W_{WP}).$$

Here W_{FC} and W_{WP} represent the soil's field capacity and permanent wilting point, respectively, and Δ_T [-] represents the crop's drought tolerance to a shortage of soil water.

For the calculations presented in this study, a set amount of irrigation water (IR = 10 mm/day) has been applied to maintain W > W_{SP}. Procedures for calculating run-off and drainage losses are described elsewhere (Green et al. 1999).

STATISTICAL ANALYSIS

The uncertain nature of rainfall over the summer months makes the scheduling and allocation of irrigation water difficult. For this reason, we used a statistical approach to examine variability in each of the water balance components. From long-term water balance calculations, we generated a probability distribution function (PDF) for each component. It is common in statistics to refer to *quantiles*. These are indexed by sample fractions. Thus:

- a Q_2 value is a one in two event (the median)
- a Q_5 value is a one in five event (a 20% probability of exceedance)
- a Q_{10} value is a one in ten event (a 10% probability of exceedance).

For the purpose of irrigation allocation, HBRC uses a Q_5 value, which aims to meet crop water needs in four out of five occasions.

RESULTS AND DISCUSSION

Representative model output for pasture on a Hastings silt loam is shown in Figures 1-4, for crop water use, rainfall and irrigation. In each case we have fitted a statistical function to the model output for each component, based on the daily water balance calculations over a 32-year sequence. The continuous lines shown in Figures 1-4 were calculated using standard functions in Microsoft® Excel (irrigation and ET are described using the NORMINV function and rainfall is described using the GAMMAINV function). The advantage of such an approach is that the level of risk (i.e. the Q-value) can be changed, if required, once the statistics and the PDF are established.

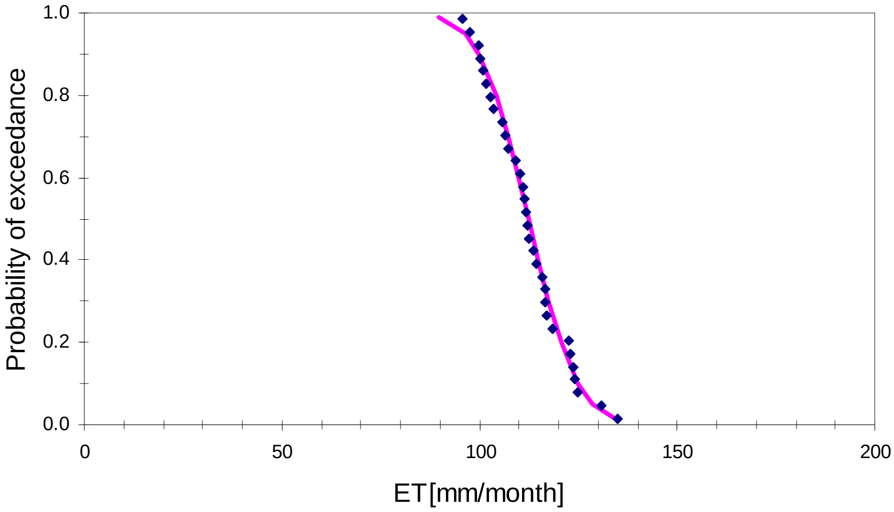

Figure 1. The probability of exceedance for pasture water use (ET) on a Hastings silt loam during the month of February. SPASMO (Soil-Plant-Atmosphere-System-Model) calculations are shown by the blue markers. The pink line represents a cumulative normal distribution fitted to the model output.

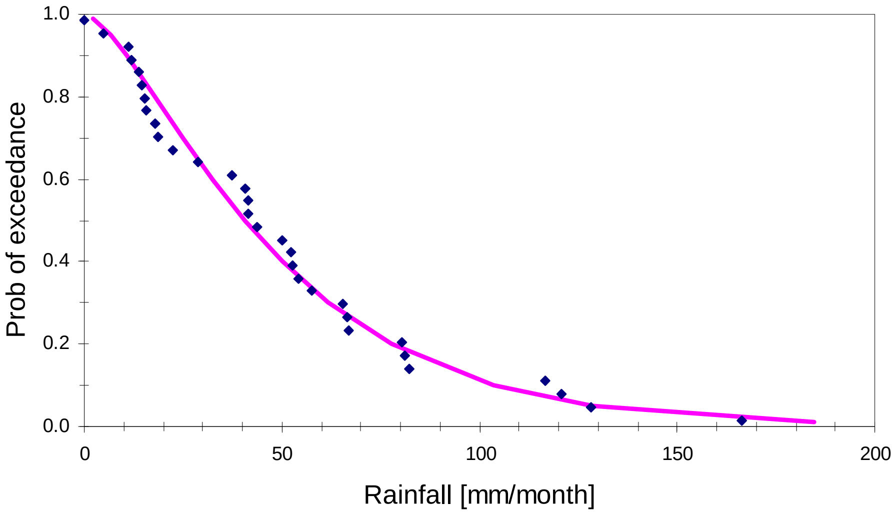

Figure 2. The probability of exceedance associated with rainfall at Hastings (NIWA Station 3017) for the month of February. SPASMO (Soil-Plant-Atmosphere-System-Model) calculations are shown by the blue markers. The pink line represents a cumulative gamma distribution fitted to the model output.

During the month of February, the following average values were calculated: ET = 112 mm, RF = 50 mm, and IR = 64 mm. However, there was quite a wide spread in irrigation needs due to the erratic and uncertain nature of summer rainfall (Figure 2). The minimum value of irrigation was 0 mm/month, while the maximum value was 110 mm/month (Figure 3). The spread in irrigation need was described reasonably well using a cumulative normal distribution. The Q_5 value for irrigation during February was calculated to be about 90 mm. This means that 90 mm of irrigation should be adequate to meet pasture needs some four out of five years, or 80% of the time, notwithstanding inefficiencies in irrigation output.

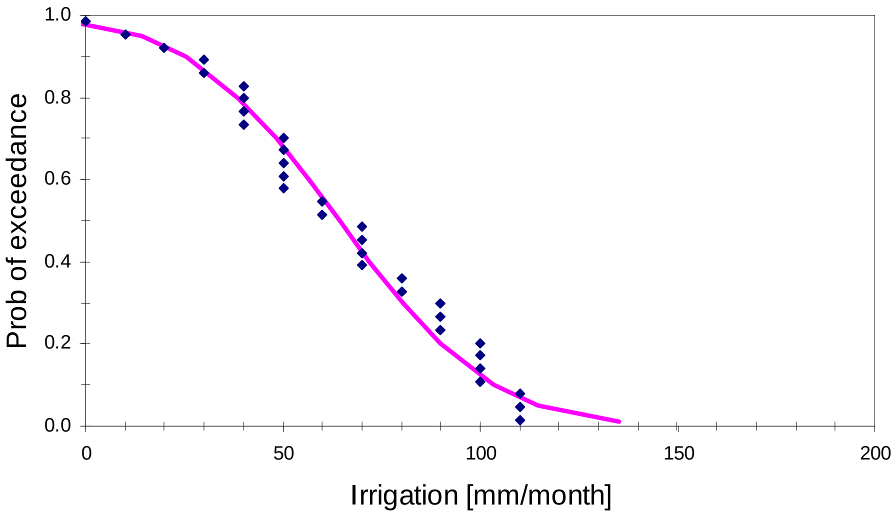

Figure 3. The probability of exceedance for pasture irrigation on a Hastings silt loam during the month of February. SPASMO (Soil-Plant-Atmosphere-System-Model) calculations are shown by the blue markers. The pink line represents a cumulative normal distribution fitted to the model output.

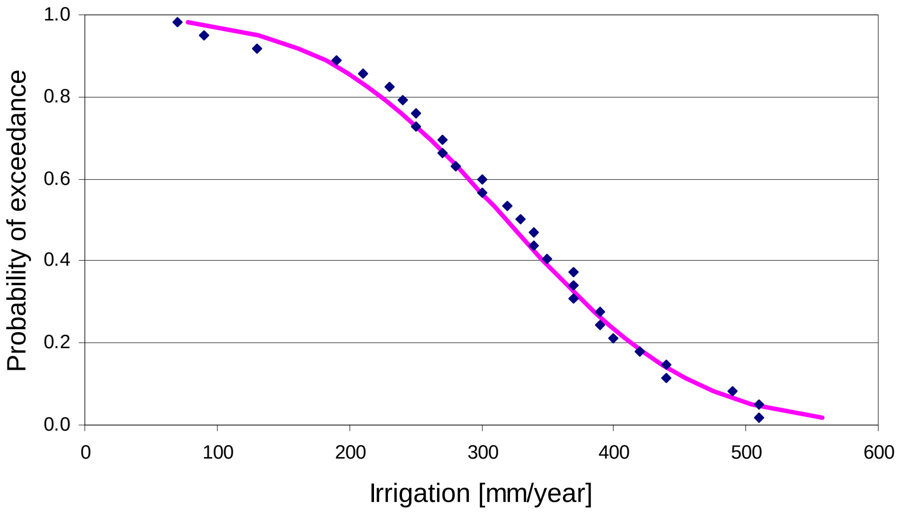

Figure 4. The probability of exceedance for the annual irrigation requirements for pasture on a Hastings silt loam. SPASMO (Soil-Plant-Atmosphere-System-Model) calculations are shown by the blue markers. The pink line represents a cumulative normal distribution fitted to the model output.

A cumulative normal distribution also provides a good description for the PDF of annual irrigation requirements. The corresponding Q_5 value for pasture irrigation was calculated to be about 410 mm/year. This means that 410 mm of irrigation should be adequate to meet the annual irrigation requirements for pasture on a Hastings silt loam some four out of five years.

COMPARING WEEKLY V. MONTHLY IRRIGATION TOTALS

Figure 5 shows the PDF for pasture irrigation during the summer months. For the purpose of comparison, weekly data have been re-scaled by the number of days in a month. During each month, the model applied a 10-mm aliquot of irrigation in order to maintain $W > W_{SP}$.

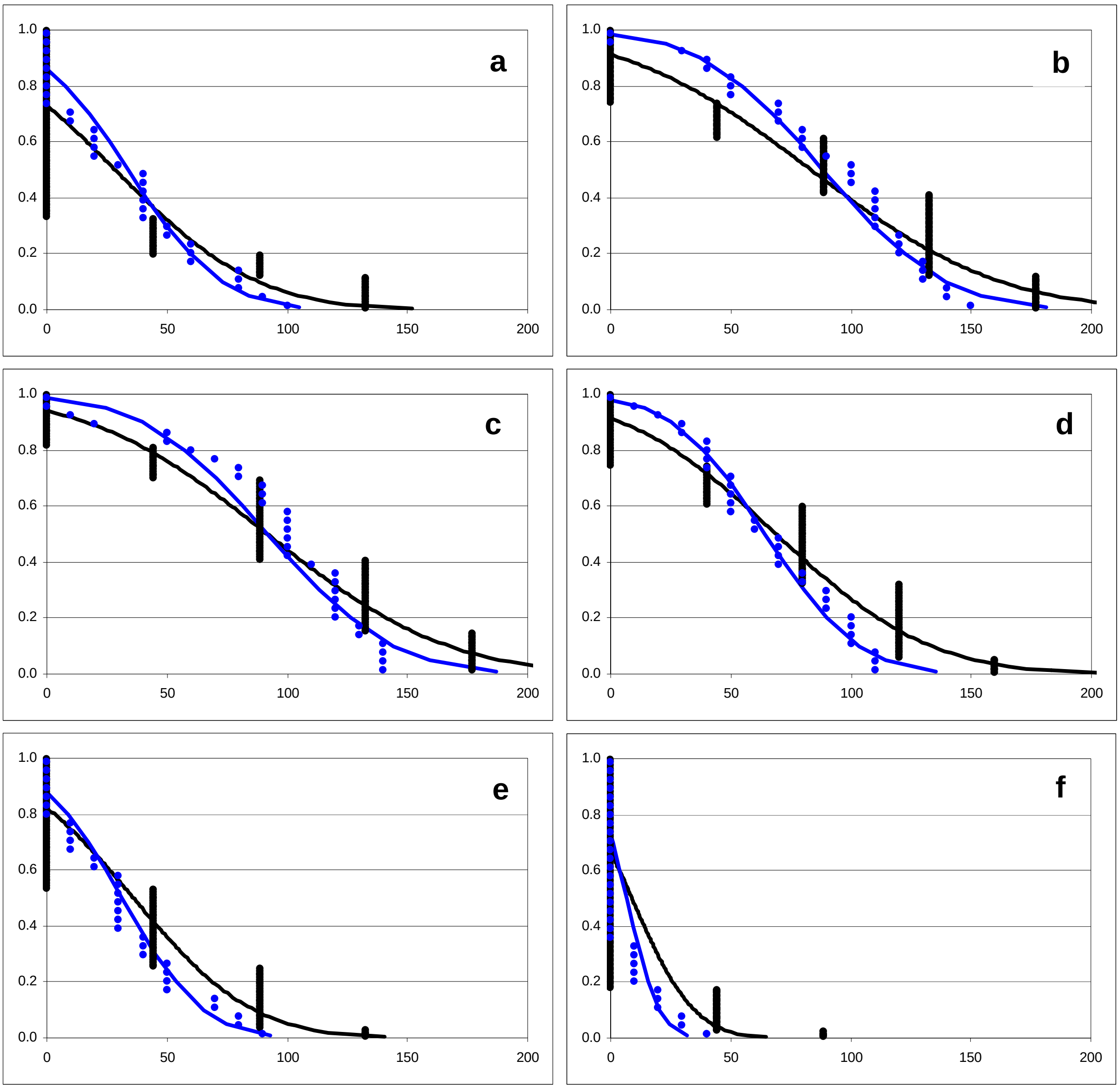

Figure 5. The probability of exceedance for pasture irrigation on a Hastings silt loam during the months of (a) November, (b) December, (c) January, (d) February, (e) March, and (f) April. The markers are model output and the lines are a cumulative normal distribution fitted to the data. Blue lines and markers are monthly data. Black lines and markers are weekly data.

On average we expect that two irrigation events of 10-mm each will be required each week to maintain adequate soil moisture levels during the month of February (black line in Figure 4d) while just one irrigation event will be needed in March (assuming regular irrigation has been applied up to that point, as needed). However, when taken over the whole month, the average number of irrigation events was calculated to be just 7 times in February and just three times in March. This was less than the 8 and 4 events that would otherwise be calculated in February and March, respectively, if one took the weekly volume and multiplied it by 4 (i.e. as has been done in the past).

Figure 5 confirms that weekly data, when scaled up by the number of days in a month, are more negatively skewed (i.e. the PDF has a larger tail towards the higher numbers) than the same calculation taken over the whole of the month. Thus, the Q_5 value for irrigation, as calculated from weekly balance data, would tend to over-estimate crop irrigation needs for the whole month. The degree of overestimation appeared to be consistent across all the summer months (Figure 6). Further, the degree of overestimation (comparing weekly v. monthly) was similar for other crops (data not shown). For that reason, we present here only the pasture analysis because that 'crop' tends to have the highest irrigation demand over the whole growing season. For comparison, while tree crops may transpire more water during late summer, they generally require less irrigation because their deeper root systems have greater access to moisture that is stored in the soil profile.

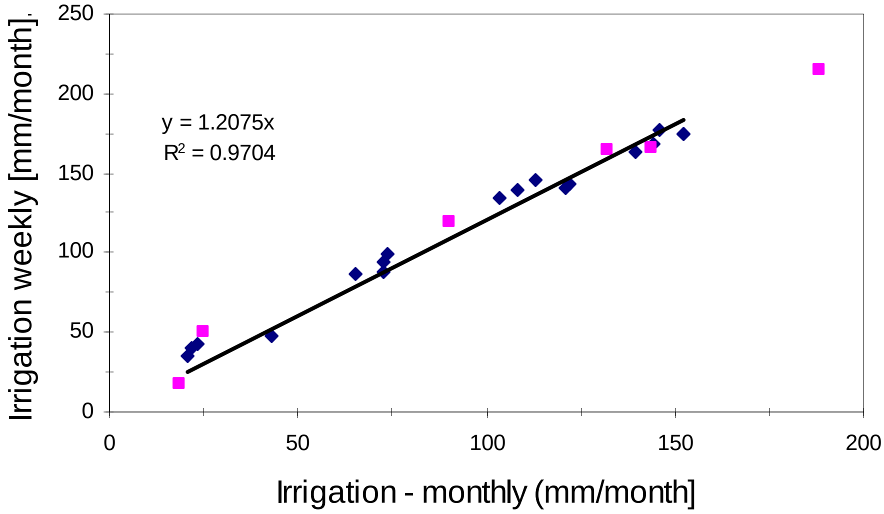

Figure 6. Relationship between irrigation allocations calculated on a weekly and monthly basis. Allocating irrigation water on a monthly basis yields ~20% lower water requirements cf. calculations based on a weekly total that were scaled by the number of days in a month.

CONCLUSION

The requirements for irrigation generally decreased as the time period increased. This is because there is a disproportionately greater likelihood of receiving some rain in any given month than there is in receiving some rain in any given week. Results shown in Figures 5 & 6 lead us to the following conclusion:

Calculating irrigation water requirements on a monthly basis yields a 20% lower water allocation requirement cf. those calculations based on a weekly period that were scaled by the number of days in a month.

The results from this study will be used to influence Council policy i.e. to decide which time step is best used in allocation of the freshwater resource for irrigation. For groundwater extractions, we expect that monthly values are more appropriate, since response times of most groundwater systems are of the order of months to years. However, for surface water takes e.g. from rivers where the recovery times are of the order of days to weeks, allocation on the basis of a weekly time period may yet be appropriate. However, the Council should be mindful that such a policy could result in an over-allocation of surface waters to the order of 20% cf. pasture irrigation needs.

ACKNOWLEDGEMENTS

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