# SUPPLY, RESTRICTIONS AND WATER USE: A SURVEY AT THE WAIMAKARIRI IRRIGATION SCHEME

**M S Srinivasan, M J Duncan**

*National Institute of Water & Atmospheric Research Limited*
*10 Kyle Street, Christchurch*
**m.srinivasan@niwa.co.nz**

## Abstract

Irrigation is the single largest user of freshwater in New Zealand and in Canterbury. While consented volumes are known, there is uncertainty about how much water is actually used for irrigation, because water use has not been widely and routinely measured. Also, there is little institutional knowledge in NZ on how to interpret water use data in the context of water resources management. The recent installation of water meters in the Waimakariri Irrigation Scheme, Canterbury, offered the opportunity for NIWA to explore water use data. We studied water use data from fourteen dairy farms from January to April 2009 and September 2009 to April 2010. These selected farms use as much as 21% of all irrigation water abstracted by the scheme. Generally, irrigation up to November was limited due to sufficient rainfall to meet evaporative demand, and was limited in March due to low flows in the Waimakariri River. Very little evidence for excessive irrigation was found, and it appeared that most users should be applying more irrigation than was measured. Detailed analysis showed that many farms appeared to build up large soil moisture deficits, and the soil moisture levels were often less than optimum for pasture growth. The low soil moisture levels were not primarily due to the lack of water availability from the scheme. Spatial and temporal analyses of historical rainfall and evaporation data across the irrigation scheme highlighted the presence of large soil moisture deficit gradients, indicating a divergent water need across the scheme. Thus, there appears to be a need to monitor soil moisture and crop needs and schedule irrigations accordingly, rather than following scheme level supply schedule. However, adoption of such monitor-and-irrigate approach would also require that farms need to develop supplementary water sources such as on- or off-farm storage, to schedule irrigation effectively.

## Introduction

Irrigation is the single largest consumptive water use in New Zealand, accounting for 77% of consented water use (Lincoln Environmental, 2000). Irrigation water use is not widely and routinely measured in all regions of NZ. Published assessments of water use are unreliable, as they are often based on the consented maximum amount of water that can be taken by each user and not the actual use. This lack of reliable information on water use has been a critical information gap in water resource management. The situation is changing rapidly, as a result of both the forthcoming National Environmental Standard for Water Metering, and the increasing pressure on the country's water resources. Extensive networks of water meters are being installed in several regions, specifically in Canterbury, the largest user of water for irrigation in the country. The data collected by these meters will be the underpinning information for the next great leap in water resources management. Here, we present results from an irrigation water use survey conducted in fourteen dairy farms within a river-based irrigation scheme, the Waimakariri Irrigation Scheme. This survey was conducted over two irrigation seasons, 2008/09 and 2009/10. Results from 2009/10 are presented and discussed here.

## The Waimakariri Irrigation Scheme

The Waimakariri Irrigation Scheme (WIS) commands an area of 44,000 hectares in North Canterbury. The scheme is bounded by the Ashley River in the north and the Waimakariri River in the south and lies between Oxford in the west and Rangiora in the east. It serves 230 shareholders that irrigate 18,000 ha, and the water is supplied via 1,400 km of channels (races) that also distribute stock water. The water source for the WIS is the Waimakariri River. The irrigation scheme is allowed to extract their full allocation (10.5 $m^3s^{-1}$) if the naturalised flows at the consent point (see Figure 1) is at or above 63 $m^3s^{-1}$. When the flow at the consent point stays between 41 and 63 $m^3s^{-1}$, partial abstraction in proportion to the flow measured, is allowed. Below 41 $m^3s^{-1}$, no irrigation abstraction is allowed. During irrigation season (October – April), 41 $m^3s^{-1}$ is exceeded approximately 95.5% of the time and 63 $m^3s^{-1}$ is exceeded 79% of the time (based naturalised time series flow records from 1967 to 2007 from de Joux, Environment Canterbury, 2009; *pers comm.*).

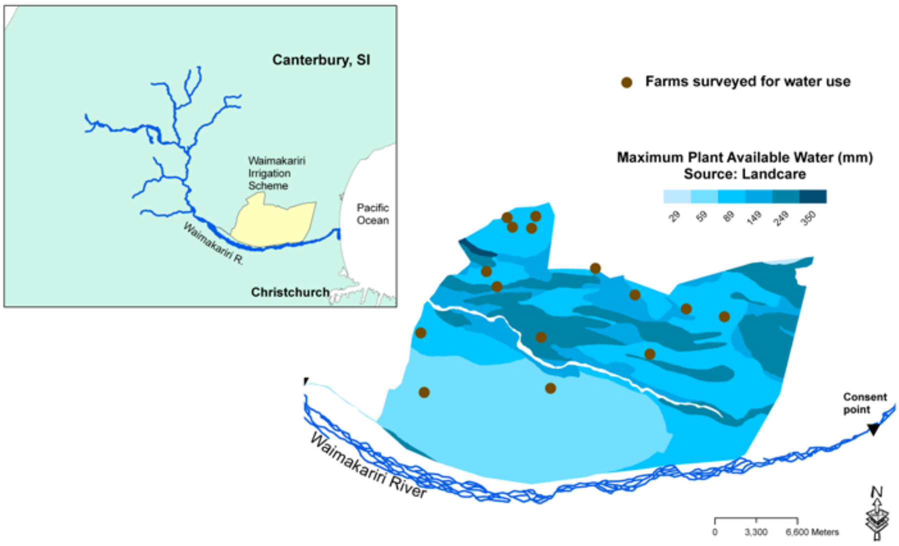


Figure 1. Location and extent of the Waimakariri Irrigation Scheme and the spatial spread of the farms surveyed for water use. Also, shown is the distribution of soils with maximum plant available water.

## Long-term climate data and trends

Based on NIWA's virtual climate network (Tait *et al.*, 2006) rainfall and evapotranspirtation data from 1972 to 2008, Srinivasan and Duncan (2011) indicated the existence of strong soil moisture deficit gradient across the irrigation scheme. They concluded that, on an average, over the entire irrigation season, farms at the eastern side of the scheme could be receiving 100 mm less rainfall and losing 100 mm more to evapotranspiration, than farms at the western side. Figure 2 shows an example of soil moisture deficit gradient for the months of December and January. These two months experience the maximum soil moisture deficit over the irrigation season, thereby needing the most irrigation. Irrigation allocations within the scheme do not explicitly accommodate these differences in soil moisture deficits. More information on the estimation of soil moisture deficit can be found in Srinivasan and Duncan (2011).

## Survey details

In February and March of 2009 all WIL (Waimakariri Irrigation Limited, the company that manages and operates the Waimakariri Irrigation Scheme) shareholders were invited to take part in the survey. The conditions for participation were that the irrigation water use was metered, and that the shareholder or his/her representative was prepared to complete a simple diary indicating the duration of irrigation and the type of crop irrigated. Nineteen shareholders, belonging to 14 farms agreed to take part in the survey. Over one third of shareholders holding more than 1000 shares agreed to take part, but only 4% of those with less than 1000 shares were part of the survey (Figure 3). So even though we sampled only 8.4% of the shareholders they accounted for 21% of shares. In other words, these fourteen farms surveyed use one-fifth of all water abstracted by the scheme.

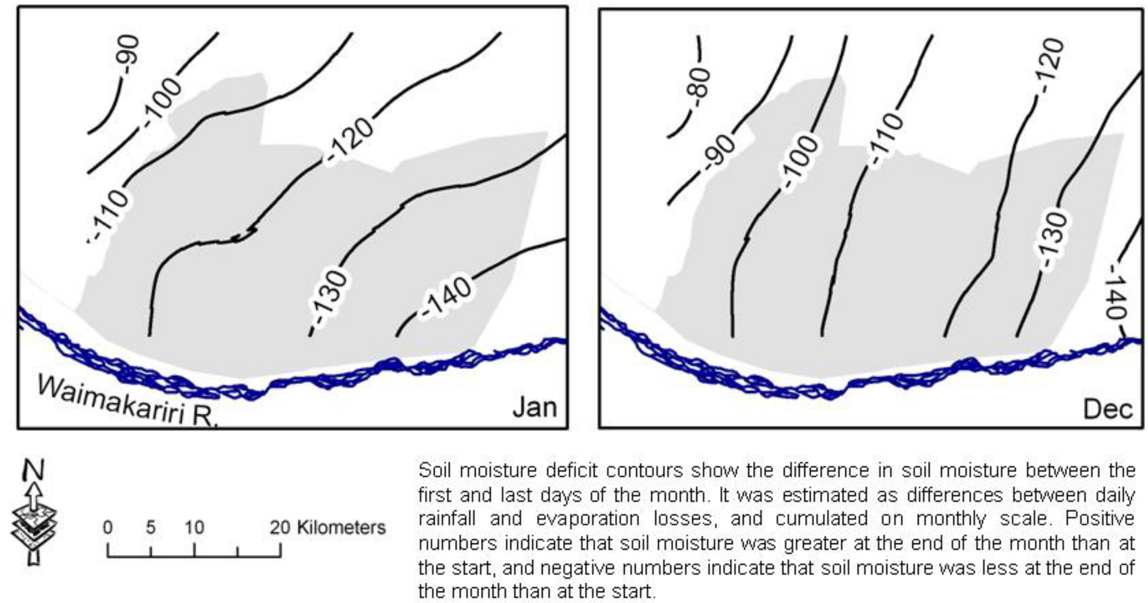


Figure 2. 5-year return period monthly soil moisture deficit contours for December and January (based on rainfall and Penman evapotranspiration data from 1972 to 2008). Adapted from Srinivasan and Duncan (2011). Extent of the scheme is shown in grey colour.

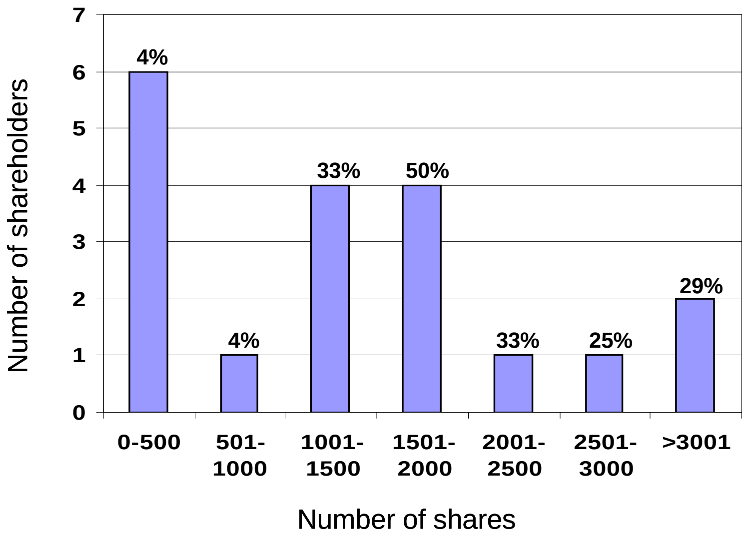


Figure 3. Distribution of shareholders in the survey by number of shares. The number above each bar indicates the proportion of survey participants in each share number range.

The distribution of irrigation water within the scheme is approximately 50% to dairy farms, and the rest to non-dairy farms. The predominant type of farming for the survey participants was dairy farming, with only two farms with mixed sheep and cropping. Eight shareholders had one or more centre pivots as their primary irrigation system, three shareholders operated big guns and two shareholders used roto-rainers. For those with centre pivots, lateral sprinklers or K-line systems were also used where the centre pivots could not reach. Some had mixed systems. Several times during the irrigation season, visits were made to the surveyed farms to download the daily water use data as well as to collect the diaries.

**Climatic conditions during 2009/10 irrigation season**

The rainfall and Penman potential evapotranspiration (PET) data at each farm were assessed using NIWA's virtual climate network (Tait *et al.*, 2006). Figure 4 shows an example dataset for a farm located near the geographical centre of the scheme. The figure shows the need for irrigation as the estimated weekly PET exceeded weekly rainfall most of the time. Seven weeks had PET greater than the consented application rate of 31.8 mm per week, and five of those 7 weeks occurred consecutively. However, only for 3 of those weeks PET exceeded rainfall by more than 30 mm.

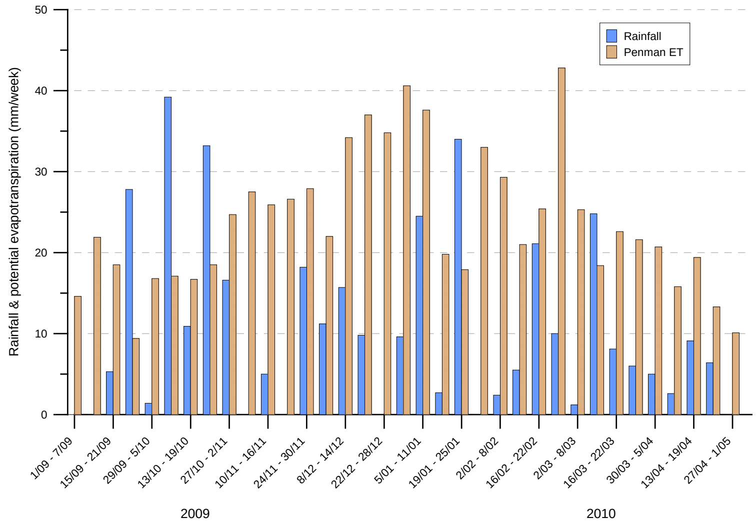


Figure 4. Weekly rainfall and evaporative losses during the irrigation season 2009/10. Data shown for a surveyed farm located near the geographical centre of the scheme.

**Survey results**

**Interpretation of week to week variability in water use – irrigation season 2009/10**

Due to faulty water meters, we could not include data from two farms in our analysis. The number of surveyed-farms irrigating during any week ranged from one to all 12 (Figure 5). Two farms had 2 pumps each and data from these two pumps were combined except where labelling indicates data for both pumps. During 2009, it was mid-November before most of the survey participants started irrigating, which probably could be due to 148 mm of rain received between September to early November. Those participants with lighter soils are presumed to have started irrigation first.

Figure 6 shows the minimum, maximum and mean irrigation applications per week from the 12 farms surveyed. During most weeks from November to February an average of 10 to 20 mm per week was applied by those irrigating, although some irrigators were applying close to the maximum design rate of 31.8 mm per week. During that period average rainfall was about 11 mm per week (depending on location). Thus, over that period the ground would have received 20 to 30 mm of water per week, and the higher figure would have been similar to the

PET for the period of 29 mm per week. Figure 6 shows maximum application rates between 40 and 53 mm per week. We suspect that these high application rates are from faulty meters rather than a reflection of actual application rates.

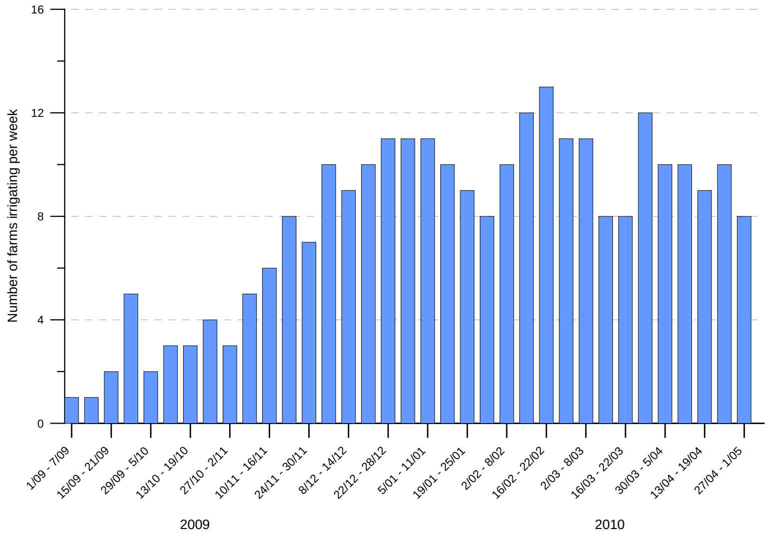


Figure 5. The number of surveyed farms that were irrigating during the 2009-2010 irrigation season – weekly irrigation data.

Figure 7 shows the weekly application rates for each farm determined from the water meter data. Again the slow start to irrigation can be seen as small applications were being made prior to December. Only on six out of 420 potential farm-irrigation-weeks (= number of weeks in the irrigation season *times* number of farms surveyed) and 237 actual farm-irrigation-weeks (= number of weeks with non-zero irrigation application), the design application rate of 31.8 mm per week was applied. This indicates that over irrigation seldom occurs. It can be seen that after substantial (>20 mm) weekly rainfalls, irrigation, often, not always, ceased or application rates were reduced. The reduced extent and rates of application in March and April are attributed to a lack of water availability from the Waimakariri River (discussed later). March and April were dry, and irrigation was continued by most participants until the end of April.

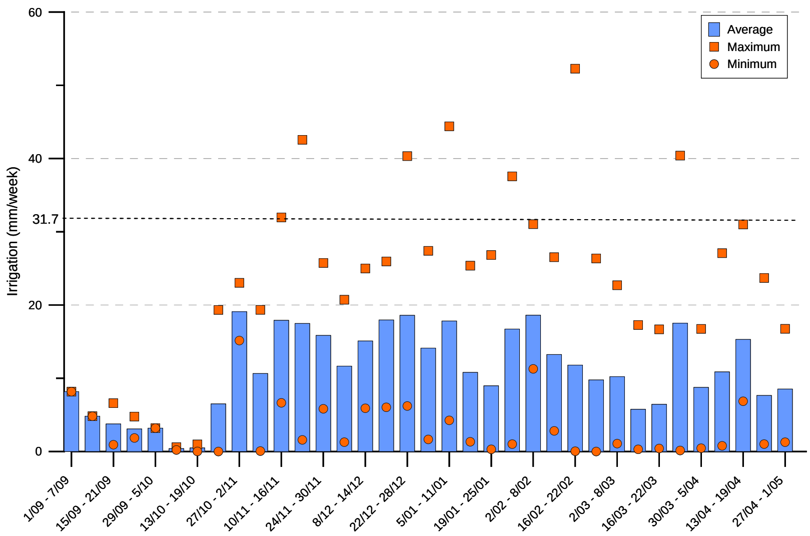


Figure 6. Weekly irrigation applications in the surveyed farms that were irrigating. Weekly supply from the irrigation scheme amounts to 31.7 mm. Data from irrigation season 2009/10.

Figure 8 shows the amount of rainfall and irrigation received per week compared to PET loss for a participant near the centre of the WIL scheme (same farm as shown in Figure 4). It shows that except for the three separate weeks early in the irrigation season when there were substantial rainfalls, there was less rainfall than was required to meet estimated PET. For about half the weeks there is a close balance between PET and rainfall plus irrigation. For four weeks there was substantially more rainfall plus irrigation than PET. We did not examine the rainfall and water meter records to see if this was the result of a timing issue i.e., irrigation followed by heavy rainfall in the same week or heavy rain at the start of a week and irrigation at the end of the week. Closer analysis of data during the irrigation season 2008/09 (Duncan *et al*., 2009) showed that where excess irrigation was apparent it was because of such timing issues, usually rainfall following irrigation. There were weeks in March and April when there was less rain plus irrigation than PET and these times coincided with times when the river was low and there was little water available to the scheme.

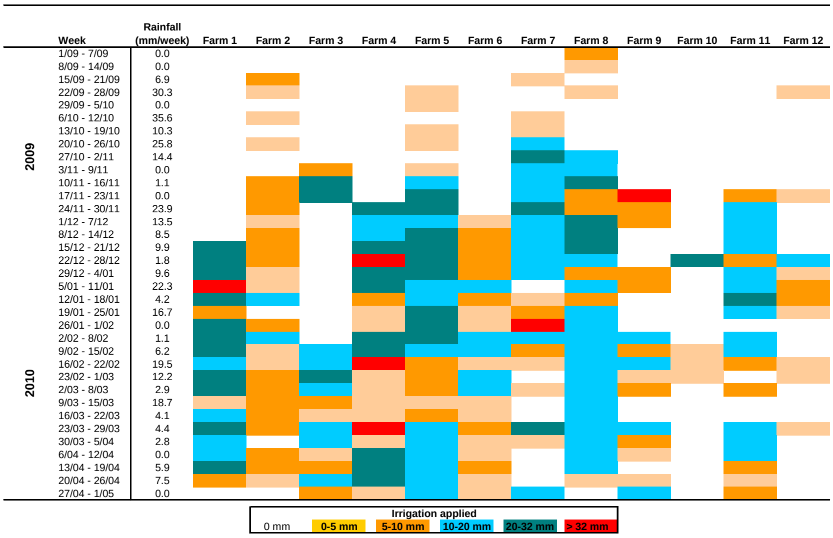


Figure 7. Weekly irrigation application from the surveyed farms. Rainfall data correspond to the participating farm closer to the centre of the scheme.

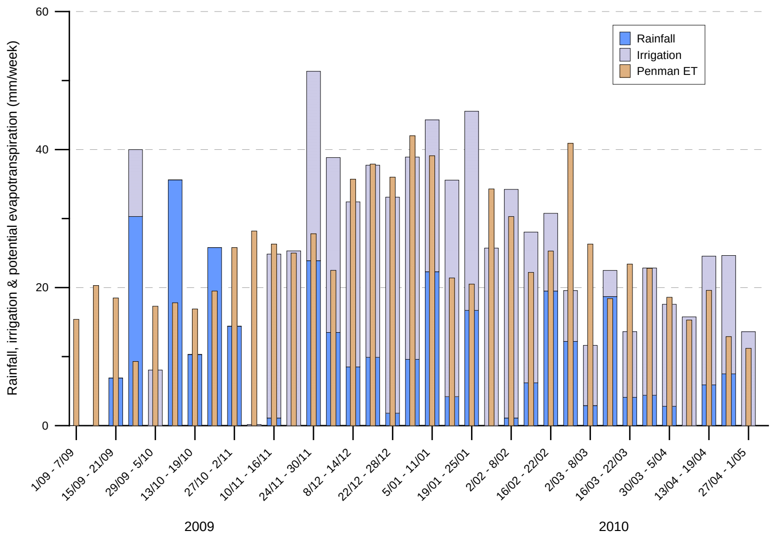


Figure 8. Weekly rainfall and irrigation compared with potential evapotranspiration for the irrigation season 2009/10 for one of the surveyed farms (same as the one shown in Figure 4).

### Availability of water to the scheme

One factor that affects water use is the availability of water to the scheme. Figure 9 shows the daily flows in the Waimakariri River at the consent point, the daily abstraction by the WIS and the weekly rainfall within the scheme. At low flows (< 41 $m^3s^{-1}$) in the Waimakariri River, the WIS abstraction is restricted to the stock water take (2.1 $m^3s^{-1}$). In October 2009 there was significant rainfall and the scheme take was low even though the Waimakariri River flows were at rates when restrictions would apply for only a few days. Later on during the season, there was less rainfall, lower Waimakariri flows and low irrigation takes. It is apparent that both the amount of water available and the rainfall affected the water take by the WIS.

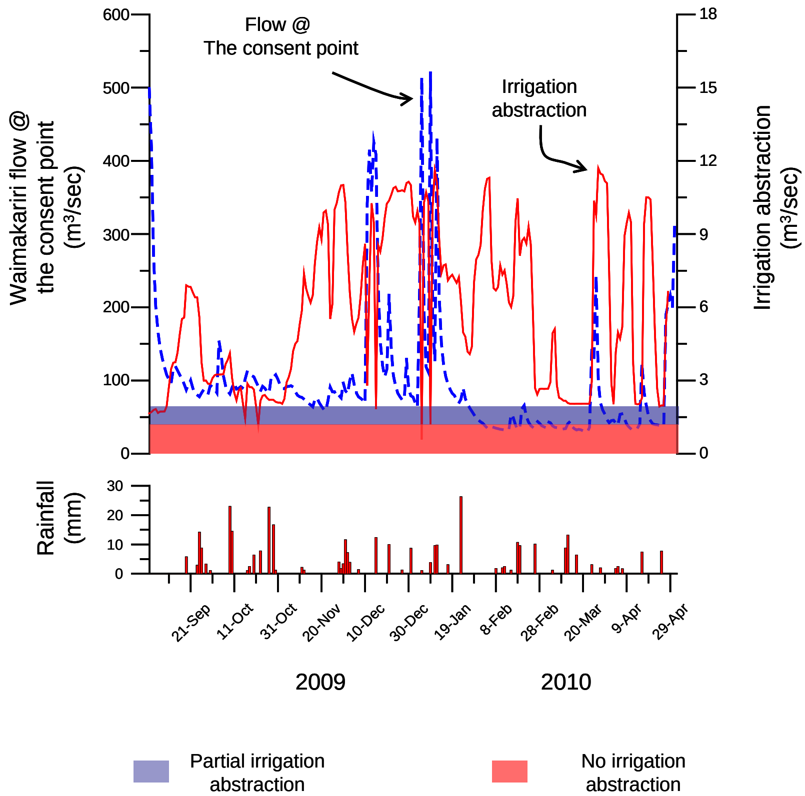


Figure 9. Flows in the Waimakariri River at the consent point (see Figure 1 for consent point location), irrigation abstracted by the WIS and daily rainfall for the irrigation season 2009/10. Adapted from Duncan *et al.* (2010)

### Adequacy of irrigation

### Accumulated soil moisture deficit

One measure of the adequacy of irrigation is to measure the accumulated soil moisture deficit. This was computed by assuming that the soil was at field capacity on 1 September 2009 (start of the irrigation season). From that the weekly rainfall and irrigation were added and the weekly PET was deducted. If the sum of those values exceeded the PAW (see Figure 1 for PAW distribution within the irrigation scheme) for the farm then soil moisture was reset to the PAW. Starting with the soil at field capacity is a reasonable assumption as NIWA’s soil moisture sensor at Rangiora (the closest climate station, located less than 10 km north-northeast of the irrigation scheme) showed the soil was at field capacity on 1 September 2009. The maximum value of the accumulated soil moisture deficit for each participant is shown in Figure 10. For those participants with large deficits, the deficit started in December and tended to grow as the season progressed. Those with smaller deficits tended to have their maximum deficits in February and the deficit became reduced as the season progressed. Large deficits indicate inadequate irrigation as measured by the meter either because of lack of supply, because the meter was under registering or because insufficient irrigation even though there was an adequate supply. Most of the large soil moisture deficits seemed to grow in December and January when water supply from the river was not limited. The irrigation manager at WIL commented that he expected a greater demand from irrigators during this period than actually occurred. This suggests that there were reasons apart from water supply that reduced irrigation application.

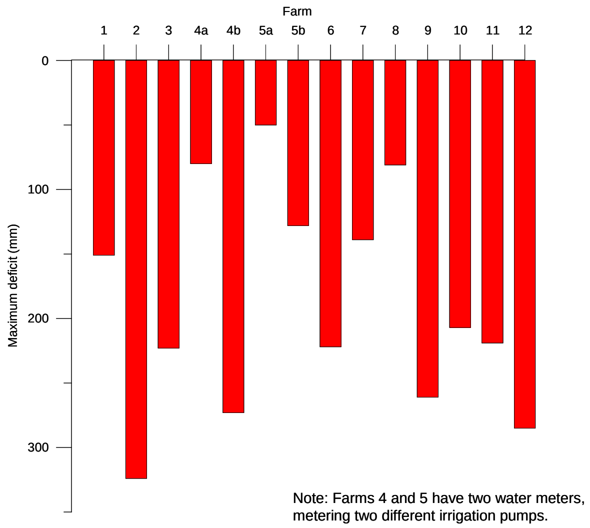


Figure 10. The maximum value of accumulated soil moisture deficit for farms surveyed during the 2009/10 irrigation season.

**Time when soil moisture was above 50% of PAW**

To maintain full pasture production, there is a rule of thumb that soil moisture levels should be maintained above 50% of PAW. Figure 11 shows the proportion of the irrigation season when soil moisture in the participating farms stayed above 50% PAW. Most of the farms surveyed have maximum PAW of 89 mm, so any deficit greater than 45 mm would indicate that soil moisture levels were less than optimum for pasture growth. There were only two farms that maintained the soil moisture levels at more than 50% of PAW for more than 75% of the irrigation season (Figure 11), and many farms had substantial soil moisture deficits indicating that soil moisture replenishment was inadequate for optimum growth for a long period.

For these soil moisture calculations, we used Penman PET and rainfall data from the virtual climate network, measured irrigation water use data from water meters and farm-specific PAW from soils map (refer Figure 1). We used similar soil moisture accounting as for the accumulated soil moisture deficit except that the weekly value was not allowed to go below zero. This method assumes that the entire PAW will be used at PET rates and we acknowledge that this will exaggerate the number of days the soil moisture is less than 50% PAW as soil moisture is used more slowly as soil moistures approach wilting point. Nevertheless we think that Figure 11 gives a good indication of how well the participants have been irrigating. It appears that in general soil moisture values are usually at lower than optimum for pasture growth with only a few farms having optimum soil moisture values most of the time. It is likely that pasture growth would still be good at values above 40% PAW and inspection of the soil moisture deficit data (not shown) indicates that a significantly higher proportion of farmers meet that criteria more often.

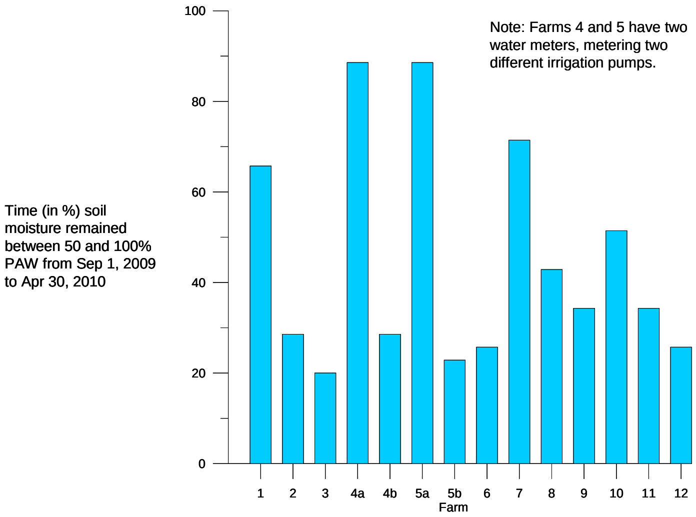


Figure 11. Proportion of the time that soil moisture was estimated to be between 50 and 100% of PAW in the surveyed farms for the 2009/10 irrigation season.

**Improving irrigation performance with soil moisture measurement**

It appears from the analysis of water use data from water meters that there is very little over irrigation and a large amount of under irrigation, and it is not very clear why low soil moisture values are so prevalent even wehn Waimakariri River water was available during many of these periods.

It is likely that soil moisture values and pasture production could be improved if irrigation scheduling was driven by soil moisture measurement rather than intuition. Interviews with farmers revealed some interest in soil moisture measurement. However, only a few farmers were using it to drive irrigation scheduling, and often there were maintenance issues with some part of the system, such as the devices used for downloading the data did not work. It was astounding to the authors that many farmers had soil moisture sensors, but were not using the data for irrigation scheduling and management. During the irrigation season 2008/09, there had been a reasonable amount of rain and most farmers used their intuition to schedule irrigation, but one particular farm was continuing to irrigate (Duncan *et al.*, 2009). Soil moisture measurements from that farm indicated that irrigation was still required regardless of the rain, but at a lower frequency than if there had been no rain. The data showed that the soil moisture levels staying between 50 and 80% of PAW. Data from that farm provided additional evidence for the need to closely match the irrigation scheduling and soil moisture needs.

It seems that the focus that some farmers have on supplementary feeding and nitrogen application needs to be equally applied to irrigation management. We strongly recommend that farmers deploy soil moisture sensors, keep them and their data retrieval and display systems well maintained and use them to schedule irrigation. Alternatively, commercial soil moisture measurement driven irrigation scheduling services are available, which are currently used by some farms within the scheme.

**Future work**

- There is a need to survey other irrigation seasons to see whether the results are typical.
- Associated with the point above is the need to further investigate the reliability of the potential evapotranspiration data to estimate evaporative demand in the WIL command area.
- There is need to have more shareholders in the survey, to provide sufficient numbers of farming types other than dairying and a wider range of irrigation methods for comparison.
- There is a need to obtain reliable daily flow data from the water meters and have a way of efficiently retrieving the data. We understand WIL is investigating a logging system that would provide real time telemetered data to a central data archive to meet this need.
- For the purpose of soil moisture deficit estimations, rainfall and PET data from NIWA's climate database (VCN) were used. However, to improve the accuracy of predictions, it is necessary that rainfall and actual evaporation data be collected within the scheme. Development of such a dataset is critical in generalising the findings for the entire scheme.

**Summary and observations**

- Early in the season the water take from the Waimakariri River was limited by demand as there was sufficient rainfall to satisfy PET until November. In March the water take and irrigation was limited by low flows in the Waimakariri River.
- The measured water use data indicate that in general there was not enough rainfall and irrigation to meet evaporative demands.
- More detailed analysis shows large soil moisture deficits built up on many farms. Very few farms were able to consistently maintain soil moisture at levels optimum for pasture growth.
- Lack of water from the irrigation scheme did not appear to be the only reason for the low soil moisture levels.
- More water storage, both on- and off-farm would reduce the likelihood of lack of water for the scheme during low flow periods.
- Soil-moisture driven irrigation scheduling may be one way to improve irrigation effectiveness.
- Some of the participants counter the supply unreliability and uncertainty by supplementing their irrigation with existing groundwater consents, but in most cases there is less water available from those supplementary sources than from the irrigation scheme. Other participants have, or are considering, on-farm storage. On-farm storage allows shareholders to take their full allocation whether or not there is an immediate need, unless their storage is full, and to use the stored water when the full supply is unavailable.
- There appears to be two approaches to storage, the first is a small pond that enables the full allocation to be taken whenever it is available (by roster) so that the allocation is not lost when irrigation temporarily stops, e.g., when irrigators are shifted; the

second approach is to have a large pond with sufficient storage, for example, for 30 days of irrigation, so that irrigation can continue at design rates even though there is a partial or full restriction on irrigation takes from the river.

- Shareholders were initially allocated 0.45 l/s/ha (27.2 mm per week), but this has recently been increased to 0.525 l/s/ha (31.8 mm per week). Many study participants considered the initial allocation to be inadequate. One shareholder interviewed considered that he was only able to deliver 22 mm per week to the grass. On average 27 mm per week delivered to the soil should be sufficient to meet the atmospheric transpiration demand of pasture, but when the application efficiency of irrigation systems is taken into account even 31.8 mm per week may be inadequate. There will be periods of dry northwest winds when PET will exceed 31.8 mm per week.
- A further constraint on irrigation efficiency that occurs when there is an unreliable water supply (as there is in this case) is the temptation to apply water to “top up” soil moisture, even when soil moisture levels are sufficient for optimum growth, when there is a likelihood of partial or full irrigation take restrictions because of impending low river flows.

**Acknowledgements**
We would like to acknowledge the support and cooperation offered by the participating farmers at the Waimakariri Irrigation Scheme and the Waimakariri Irrigation Limited. This study was funded by the FRST programme WaterScape CO1X1006.

## References

Duncan, M.J., Srinivasan, M.S., Diettrich, J. 2009. Improved irrigation management via water metering information. *NIWA Client Report CHC 2009-094*. 24 p.

Duncan, M.J., Srinivasan, M.S., Diettrich, J. 2010. Improved irrigation management via water metering information: 2009-2010 irrigation season. *NIWA Client Report CHC 2010-091*. 26 p.

Lincoln Environmental. 2000. Information on Water Allocation in New Zealand. Ministry of Environment, Wellington, New Zealand. <http://www.mfe.govt.nz/publications/water/water-allocation-apr00.pdf> (May 10, 2010).

Srinivasan, M.S., Duncan, M.J. 2011. Droughts and irrigation reliability: an investigation of a river-based irrigation scheme in New Zealand. *Journal of Irrigation and Drainage Engineering (in review).*

Tait, A., Henderson, R., Turner, R., Zheng, X. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology* 26: 2097-2115.