Lessons from an evaluation of automated bay irrigation of pasture and fodder

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Abstract
Automation of surface (bay) irrigation is now a commercial reality. Automation provides increased certainty in irrigation management. However in the absence of appropriate decision support, key decisions, such as the scheduling of irrigations and irrigation duration, still rely on the skill of the irrigator. Over the 2013/14 irrigation season the authors evaluated the application efficiency achieved by farmers who had adopted automated bay irrigation, the trial involving 9 farms x 1 bay x multiple irrigations.

The results demonstrated that irrigation application efficiencies in excess of 90% are achievable and are being achieved through correct and precise management of the automated irrigation. Four of the farms evaluated are already operating at that level. For the others, strategies were identified that will raise their efficiency close to or above 90%. As well a number of not unexpected lessons relating to the irrigation management were learnt from the trial.

Key Words
Surface irrigation, application efficiency, irrigation duration, soil moisture

Introduction
An earlier study by the Cooperative Research Centre for Irrigation Futures (Smith *et al*., 2009 and Gillies *et al*., 2010) showed that average irrigation application efficiencies on bay irrigated dairy farms in the Goulburn Murray Irrigation District (GMID) in northern Victoria, were relatively low, at about 69%. It also showed that significant gains in efficiency (~20%) were possible by the simple expedient of doubling flow rates (to at least 0.2 ML/d/m width) and reducing irrigation durations. However at these higher flow rates and reduced times the irrigation performance is particularly sensitive to the irrigation duration or cut-off time.

Modernisation (automation) of the channel supply system in the GMID, under the government funded FoodBowl project, has responded to the work of Smith *et al*. (2009) and Gillies *et al*. (2010) by increasing the rate of supply available to growers from about 10 ML/d to near 20 ML/d, thus providing growers with the opportunity to increase their application efficiency. For growers seeking Federal Government support for on-farm efficiency improvements, GBCMA (2012) used the above work of Smith *et al*. (2009) and Gillies *et al*. (2010) to arrive at the recommended flow rate to the bay of 0.2 ML/d/m width.

A number of farms in the GMID have installed on-farm automation systems (as well as adopting the recommended higher flow rates), thus providing greater precision and certainty in the management of irrigation duration. Hence the objective of this study was to quantify the gains in application efficiencies possible through the use of optimally-managed, automated, high-flow bay irrigation and to demonstrate what can potentially be achieved from farms now supplied from a modernised irrigation supply system.

Evaluation Methodology
The GMID is located on an alluvial plain with soils that range from coarse sands deposited adjacent to former streams to fine textured, cracking clays from deposition of fine material remote from stream channels (Butler, 1950). Bay irrigation is the predominant irrigation method for pastures (perennial and annual) and fodder crops in the region. Annual average rainfall is between 350 and 500 mm, with annual average potential evapotranspiration of approximately 1300 mm.

The nine bay irrigation farms participating in the trial (Table 1) had invested in the Rubicon FarmConnect™ on-farm automation infrastructure, which in most cases had been in operation for a full irrigation season. The evaluation process used was similar to the Irrimate™ commercial irrigation evaluation process described by Dalton *et al*. (2001). Flow rates into the trial bays were inferred from measurements at the supply point to the farm. Irrigation advance and flow depth were measured at three points down each bay using Rubicon FloodTech depth sensors. Soil moisture was monitored continuously in each trial bay. All data were collected automatically and stored on-line.

Table 1. Details of the trial bays.

Farm	Bay Width (m)	Length (m)	Slope	Crop	Soil Type[1]	Flow Rate (ML/d)[3]
L	40	392	1:883	Lucerne	Goulburn loam (IV)	18 (0.45)
Q	45	450	1:635	Lucerne	Shepparton fine sandy loam (II)	10 (0.22)
P	50	400	1:390	Lucerne	Lemnos loam (III)	25 (0.5)
T	50	400	1:916	Maize	Moira loam (III)	14 (0.28)
I	50	548	1:426	Soybean	Youanmite loam (II)	21 (0.42)
M	80	340	1:682	Perm pasture	Not surveyed[2]	20 (0.25)
R	80	266	1:336	Perm pasture	Shepparton fine sandy loam (II)	14 (0.17)
D	68	294	1:723	Perm pasture	Fenihurst clay loam (IV)	10 (0.15)
G	42	310	1:508	Perm pasture	Mologa loam (III)	16 (0.28)

[1] Skene (1971) and Skene and Poutsma (1962)
[2] Most likely a group (IV) soil such as Goulburn loam, Goulburn clay loam or similar
[3] Figures in brackets are the flow rates per unit width (ML/d/m width)

The key performance measure used in the evaluations was the application efficiency which is defined as:

$$\text{Application efficiency (Ea)} = \frac{\text{volume (or depth) of water added to the root zone)}}{\text{total volume (or depth)of water applied to the bay)}}$$

and where losses occur principally as tail-water runoff and deep percolation though the root zone.

The model used in the evaluations was the Surface Irrigation Simulation Calibration and Optimization model (SISCO) developed by Gillies and Smith (2015). The model requires the physical characteristics of the bay, i.e. length, width, and slope of the bay, as well as the flow rate onto the bay, the soil infiltration characteristic and the resistance provided to the flow over the bay by the crop or soil surface. This latter characteristic is indicated by the Manning n, the roughness term in the well-known Manning flow equation.

SISCO is self-calibrating. In calibration mode, it estimates the soil infiltration parameters and roughness parameter (Manning n) from the measured inflow hydrograph and any combination of the advance data, runoff hydrograph, water depth measurements and recession times measured during the actual irrigation event. Once calibrated the model provides an accurate simulation of the given irrigation and was used to estimate the application efficiencies and the depths of infiltration along the length of the bay. It can also be used to determine the effect of varying the flow rate and irrigation duration (time to cut-off) and thus determine the preferred or optimum irrigation for the given conditions.

Results of Evaluations

The results from the evaluations, summarised in Table 2, demonstrate that application efficiencies in excess of 90% are indeed achievable and being achieved through correct and precise management of automated surface irrigation. Four of the farms evaluated in this study are already operating at that level. For four of the other five farms strategies were identified that will raise their efficiency close to or above 90%. On the remaining farm (farm G) soil limitations preclude any improvements in efficiency on the trial bay. Fortunately this bay is not representative of the remainder of the farm where higher efficiencies would be expected.

Table 2. Summary of results.

Farm	No of Irrigations	Mean Application Efficiency* (%)	Recommended Action
A	6	95	Nil required
B	1	87	Monitor more events
C	5	92	Nil required
D	9	74	Reduce time to cut-off to 100 min
E	5	63	Irrigate less frequently, **reduce flow rate**, cut-off when advance reaches 70% of length
F	6	68	Cut-off at 90 min, irrigate less frequently and at consistent soil moisture
G	7	63	None possible - conduct further trials on a more representative bay
H	2	90	Cut off when advance reaches 50% of length
I	5	56	Grade bay, flow rate 20 ML/d, cut off at 100 min & re-evaluate

It is interesting to note that on average the farmers growing fodder crops performed better than those irrigating permanent pasture. Reasons for this were:

- selection of irrigation durations to minimise runoff,
- greater soil moisture depletion prior to irrigation and hence larger irrigation applications, and
- greater consistency in the use of the soil moisture data in deciding when to irrigate.

There is of course no reason why all irrigators could not follow these same principles.

The stand out performer was farm A where very consistent management was applied, commencing each irrigation at about the same moisture content (soil moisture deficit of 90 mm) and using constant irrigation durations (90 min) that minimised tail-water runoff. Application efficiencies on this farm were consistently high, between 90 and 100%.

Lessons Learned

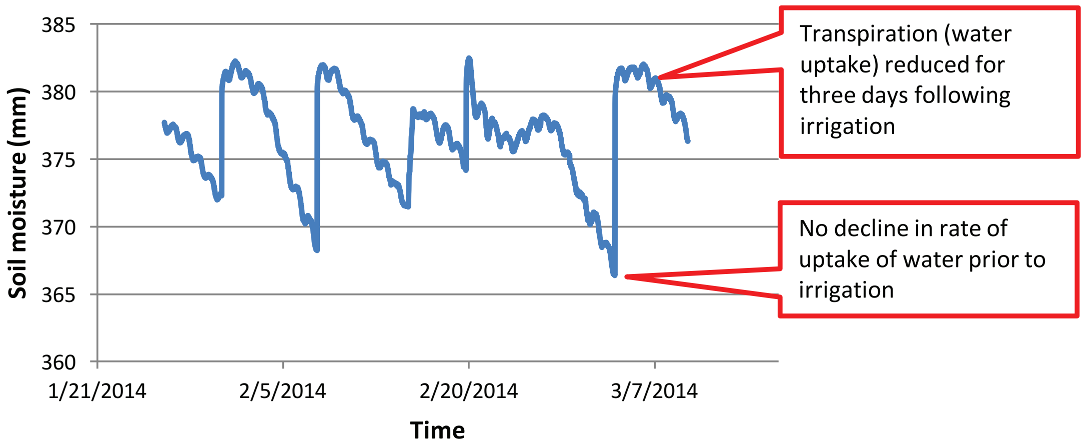
As well as quantifying efficiencies, the observations and circumstantial evidence from the trial suggest the following lessons might apply, namely:

1. Excessively long irrigation durations are the principal cause of low efficiencies.
2. Soil moisture data is crucial for the optimal management of irrigated pasture and should lead to increased irrigation intervals.
3. Pastures are deeper rooted and/or are drawing water from deeper in the soil profile.
4. Waterlogging is a major consequence of inefficient surface irrigation.
5. Less frequent irrigations and shorter durations will reduce the incidence of water logging and should give greater pasture productivity.

Together they suggest the possibility of substantial change to the way bay irrigated pastures are managed.

Pastures certainly appear to be irrigated too frequently. For example in the soil moisture trace of Figure 1, there is no evidence of decline in the rate of uptake of moisture in the day immediately preceding each irrigation, i.e. soil moisture prior to irrigation is still well above the true refill point. Further the figure also shows that the pasture is drawing moisture from below the deepest sensor, suggesting that the effective root zone of the pasture is deeper than most growers presume. This means larger soil moisture deficits and greater irrigation intervals should be possible without the pasture suffering stress or yield decline. This notion is supported by the successful management on farm H that irrigated on a 12 to 15 day irrigation interval during the same period as shown in Figure 1 without any apparent detriment to the pasture yield or species mix.

Figure 1. Soil moisture trace for farm F during Feb 2014.



Irrigation evaluations show irrigators typically applying 30% more water to the field than is required to replenish the soil moisture deficit. The result is excessive tail-water runoff and deep percolation losses (along with significant nutrient loss), extended periods of drainage following irrigation, residual water remaining in the micro-topography of the field, and water-logging of the surface soils. Soil moisture probe data (Figure 1) shows that this can cause the pasture to shut down and cease transpiring for 2-3 days after irrigation with consequent loss of productivity. Two days loss of growth following each of 10 irrigations in a season amounts to a potential loss of production in excess of 20%. These periods of extreme wetness also reduce the time available for grazing.

Incorrect (excessive) irrigation durations are the prime cause of inefficiency (over-irrigation), leading to runoff and/or deep percolation losses. The previous work has shown that correct selection of irrigation duration can maximise application efficiency and eliminate waterlogging. As farmers move to higher flow rates the need for accuracy and precision in the selection and management of irrigation duration becomes even more critical.

A prime example of the importance of irrigation duration is farm F. Six irrigations at this site were available giving an average application efficiency of 68% (range 61 to 78%) with the entire loss being tail-water runoff resulting from excessive irrigation durations. Reducing the irrigation duration to 90 min (from the current 120 min) would reduce the tail-water runoff substantially and raise the application efficiency to about 90%. It would also eliminate the long drainage times and the presence of free water remaining on the surface of the bay following completion of the irrigation and thus contribute to reducing the incidence of waterlogging.

Conclusion

The evidence (observational and circumstantial) suggests a sea-change is required in irrigation management that will lead to more productive, water use efficient, and environmentally friendly bay irrigated pastures. The features are:

- high flow rates to minimize water losses to deep percolation,
- automation to give precise control of irrigation durations,
- real-time selection of irrigation duration to optimize performance thus eliminating run-off losses, and
- consistent management based on soil moisture monitoring.

Together they should:

- mean less frequent and deeper irrigation applications and higher irrigation application efficiencies,
- eliminate residual water on bays and reduce waterlogging,
- increase pasture productivity and create longer windows for grazing, and
- increase opportunities for utilization of incident rainfall.

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References

Butler BE (1950) A theory of prior streams as a causal factor in the distribution of soils in the Riverine Plain of south eastern Australia. Australian Journal of Agricultural Research 1, 231–252.

Dalton P, Raine SR and Broadfoot K (2001) Best management practices for maximising whole farm irrigation efficiency in the Australian cotton industry. Publication 179707/2, National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba.

GBCMA (2012) Farm Water Frequently Asked Questions (FAQs) Round 3 - On farm irrigation efficiency program. Goulburn Broken Catchment Management Authority (GBCMA), accessed at http://www.gbcma.vic.gov.au/images/2012 20- faqs r3 - september - updated.pdf on 18 March 2013.

Gillies MH and Smith RJ (2015) SISCO – Surface irrigation calibration and optimisation. Irrigation Science (in press)

Gillies MH, Smith RJ, Williamson B and Shanahan M (2010) Improving performance of bay irrigation through higher flow rates. Irrigation Australia Conference and Exhibition, Sydney, 8-10 June.

Skene JKM (1971) Soils and Land Use in the Mid-Loddon Valley, Victoria. Technical Bulletin No 22, Victorian Department of Agriculture, Melbourne, Australia.

Skene JKM and Poutsma TJ (1962) Soils and Land Use in Part of the Goulburn Valley, Victoria. Technical Bulletin No 14, Victorian Department of Agriculture, Melbourne, Australia.

Smith RJ, Gillies MH, Shanahan M, Campbell B and Williamson B (2009) Evaluating the performance of bay irrigation in the GMID. Irrigation Australia, 2009 Conference, Swan Hill, Vic, 18 – 21 October.