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Water saving through smarter irrigation in Australian dairy farming: Use of intelligent irrigation controller and wireless sensor network

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Abstract: Precise control of irrigation water for improving water use is critical for sustainability of irrigated farming systems under Australia's present water crisis scenario. Border-check irrigation is the predominant method of irrigating dairy pastures, which is the single largest water user in the country.

As a classical practice of border-check irrigation, cut-off of the water supply is determined when the waterfront reaches two third of the irrigation bay. In these practices, irrigation requirement may not have fulfilled or there may be increased deep percolation and/or water logging, which lead to lower economic water and pasture productivity. In order to address these issues, a sensor based border-check irrigation system (Real Time Intelligent Irrigation Controller - ARTIIC) has been developed that includes a real time feedback control.

The system consists of a wireless sensor and actuation network, a central host/user interface, which collects stores and displays real time information, and central control system software. ARTIIC, which analyses data and reports in real time, plays a dual role scheduling and monitoring irrigation events. ARTIIC has two main components Automated Real Time Controller (ARTC) and Intelligent Irrigation Controller (IIC).

A wireless sensor network (WSN) comprised of probes/sensors was installed in a trial dairy farm located in Dookie, Northern Victoria, Australia, to capture and store data in real time into a SQL Server database at a set uniform time interval. This paper describes the core component, Intelligent Irrigation Controller (IIC) of ARTIIC, which uses and analyses data downloaded by the WSN. IIC can make event based unsupervised estimation of irrigation parameters and runoff using a kinematic wave model, based on a linear infiltration model and the Manning Equation followed by unsupervised estimation of optimal time to cut-off, which is then passed to ARTIIC. Unsupervised features of IIC is capable of facilitating automation in the real time control environment.

The new irrigation control of IIC is currently under evaluation at the trial farm in Dookie, and initial results indicate up to 43% (average 38%) water saving over conventional irrigation control methodologies. In this paper authors are focusing on IIC, which is the core model that facilitates the irrigation control.

Keywords: Wireless Sensor Network, Border-check irrigation, Irrigation parameters, Time to Cut-off, water saving, Intelligent Irrigation Controller, Automated Real Time Intelligent Irrigation Controller, IIC, ARTIIC.

1. INTRODUCTION

The precise control of irrigation water for improving water use is critical for sustainability of irrigated farming systems under Australia's present water crisis scenario. Border-check is the predominant method of irrigating dairy pastures, which is the single largest water user in Australia (Robertson et al., 2004). The water account report from the Australian Bureau of Statistics indicates that overall total water consumption of the dairy industry is about 17% of national water resources or of allocated water.

As a practice, current criterion in border-check irrigation is to end water supply when the advancing waterfront from the supply gate reaches about two thirds of the dairy field (bay) or guessing adequacy of the soil moisture within the root zone. Although the usual irrigation practice has been the arrival of waterfront in two third of the bay, the authority of the farm sometimes decides the termination point of water supply to the field by watching the advancing flow and guessing the wetness of the irrigation bay, which is ultimately become a human guess.

In both cases, it is uncertain whether the field is over irrigated or under irrigated. Over–irrigation loses water in terms of deep percolation, water logging and high runoff resulting in stress in pasture growth. Under-irrigation creates insufficient water for pasture growth and stress. In addition, a minimum of four hours labour is involved in capturing the determining waterfront, 2/3 of a bay length or using the guess method.

The IIC was developed to address these issues. It consists of two sub systems, Investigation System and the Application System. The Investigation System computes irrigation parameters and then applies them in Application System, which calculates optimal irrigation time.

Creation of the IIC was based on data collected from a field trial conducted in the 2006/2007 and 2007/2008 summer irrigation seasons. Parameters that the IIC are based on includes the rectangular trial bay assumed to be in uniform slope along the field length and well (laser) levelled, and no slope along the width. Furthermore, the soil type and strength were uniform throughout the bay.

In addition to the field conditions described above, the IIC is has been developed using linear infiltration function, and the Kinematic Wave Theory for infiltration and overland flow. The objective of this paper is to demonstrate the capabilities of IIC regards to water saving and its self determination towards automation in dairy farming water use control.

2. STUDY AREA

The Dookie College campus of the Institute of Land and Food Resources (ILFR), University of Melbourne, is located in Dookie of Northern Victoria, Australia (Figure 1). The campus property itself is about 2,500 ha reserved as Crown Land, predominantly for agricultural education (Land Conservation Council 1983). The Dookie Bushland Reserve is comprised of an area of 150 ha of Low Rises Grassy Woodland and 120 ha of White Box Grassy Woodland, also located on the campus (Adam and Steve, 2001).

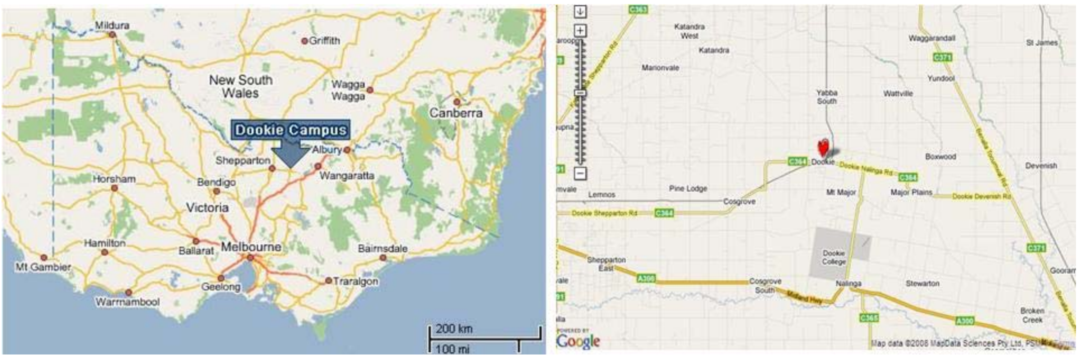

Figure 1. Location of Dookie and Dookie Campus Dairy

A permanent weather station located at Dookie College indicates the climate to be typically Mediterranean. Annual rainfall is above 500 mm out of about 100 rainy days (mostly during winter), and there are generally about 20 frost days between April and September. There are approximately 12 hours of direct sunlight during summer with possible temperatures above 40^0C. Evaporation exceeds rainfall during the period from September to April.

Sandwiched between the Midland Highway and the Broken River, The Dookie Campus Dairy and its herd predominantly accommodate Holstein and Jersey Holstein Cross cows bred from selected Genetics Australia sire. Dairy trial farms are situated closed to the herd (Figure 2).

The picture 4 of Figure 2 shows the typical bay, labelled 12, used for our irrigation experiments. Water supply to trial bay 12 is from the Broken River (picture 1) pumped through the channel (picture 3) whilst the pumping station is shown at picture 2 of Figure 2.

Figure 3 shows the location of sensors in the aforementioned trial dairy (picture 4 of Figure 2) field. The sensors 1 and 2, located at 146m and 220m inside the bay are deterministic devices from which the IIC captures the times taken for the waterfront to reach those points.

Figure 2. 1 – Broken River the irrigation water supply stream; 2 –Pumping station that pumps water to the channel from the river; 3 – Water supply channel; 4 – A trial dairy farm and supply (flume) gate

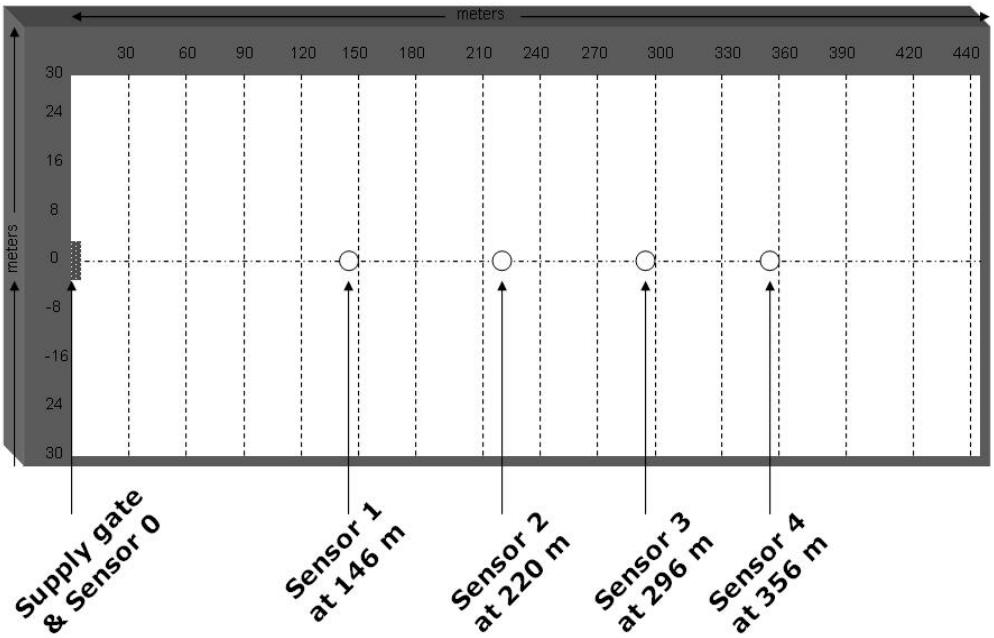

Figure 3. Schematic diagram (plan) of the trial farm bay and locations of the sensors. The bay slopes slightly downwards (right side)

3. MODEL DEVELOPMENT

3.1. Base Models

The governing equations for the irrigation parameters of the Investigation System of IIC are the linear infiltration model and the Kinematic Wave Model (Austin and Prendergast., 1997) shown in Equations (1) and (2).

$$Z = Z_{cr} + i_f t_{op} \quad (1)$$

where Z_{CR}: initial infiltration (depth of water rapidly infiltrating into cracks), i_f : final infiltration rate and t_{op}: opportunity time.

$$t = \frac{my_o}{i_f}\left[1-\left(1-\frac{i_f}{q_o}x\right)^{1/m}\right]-\frac{Z_{cr}}{i_f}\ln\left(1-\frac{i_f}{q_o}x\right) \quad (2)$$

where x: flow's travel distance, t: time taken for waterfront to travel distance x , q_o: inflow rate, m: empirically fitted constant (m = 5/3) and y_o: flow depth when x = 0.

The application efficiency is the ratio between the average depth infiltrated into the root zone and average depth of water applied to the field, whilst the distribution uniformity is the ratio between average infiltration at the end quarter of the field and that for the entire field.

A solution was found based on a numerical analysis performed using these equations at an irrigation event. The criteria for an optimal solution for maximum throughput, that is infiltration from irrigation and water saving, were set in such way to reach the waterfront passing the end of the bay whilst receiving the highest possible application efficiency and distribution uniformity for the irrigation. The criterion the authors have found that satisfies the maximum throughput is given by the following Equation, assuming the inflow rate is constant:

$$\frac{\partial W_w}{\partial T_{co}} = q_o \quad (3)$$

where W_w is the loss of water based on requirements and T_{co} is the irrigation time.

3.2. Data for the Model

Data is received via the WSN to an SQL server database located in the site office computer. Temporal soil moisture data for each location and the sensor including flume gate sensor (picture 4 of Figure 2), is stored in this database. The times of gate opening and for the waterfront to reach the sensors at 146m and 220m locations (senor 1 and sensor 2 of Figure 3) along the bay are captured either in real-time or as manual readings, depending on the system applied (on top of the IIC). This information is then passed into another database that has been setup for the IIC model.

The ARTIIC is visualized as shown in Figure 3. Two sub components of IIC, the Investigation System (IS) and the Application System (AS) are also depicted. Sensor related data (focus on this paper) is received (blue arrow) by IIC component from WSN either manually or in real time.

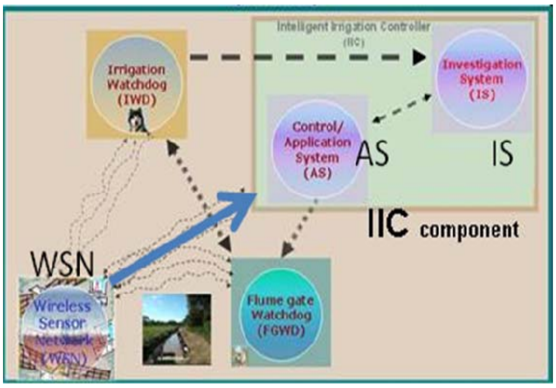

Figure 4. Schematic diagram of ARTIIC and its components. Sensor data received via WSN (manually or automated) is captured by IIC

3.3. Estimated Irrigation Parameters and Time to Cut-off

Upon reception of times to reach the aforementioned sensor points, the user interface of the IIC provides the path to the solution as shown in Figure 4.

When the aforementioned times, inflow rate and bay geometry are entered, appropriate irrigation parameters are produced. Clicking on (manual) or triggering (automated), the 'Confirm Req Infiltration Depth' button calculates the optimal time to cut-off.

Figure 5. IIC. Left: Estimating irrigation parameters. Right: Estimating optimal time to cutoff

4. RESULTS

Averages of actual and estimated times for the waterfront to reach three positions at 146m, 220m and 296m of the bay in 8 irrigations are shown in Table 1. Absolute deviations of estimated times are lower than 10% from the actual values, which confirms the validity of the model. In this regard, authors were able to develop two solutions (Eigen-solutions in an Eigen space), from which the best solution found is depicted in Table 1. Both solutions give results close to actual data received from irrigation experiments.

Table **1.** Averages of arrival times of waterfront, plus deviations and percentages of estimates from actual times

Average				
	Time of arrival of water front - min		Deviation from Actual	
Distance	Actual	Estimated	Deviation	%
146	166	163	-2	-1
220	268	248	-20	-8
296	369	341	-28	-8

Both Investigation and Application systems perform analyses, unsupervised calculation of irrigation parameters and optimal time to cut-off. This unsupervised nature can be integrated into real-time environments so that the system can provide an automated water control system, which reduces the labour cost.

Figure 5 is the visually depicted the optimal time to cut-off or irrigation time held on 18th of March 2008. It displays the diminishing or zeroed infiltration rate beyond the critical point shown, and is similar for all of the irrigation events.

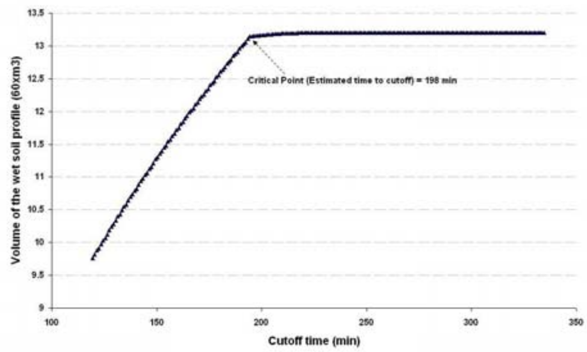

Figure 6. Optimal time to cut-off, or the critical point

Comparison table between human guess and IIC estimated optimal times to cut-off (T_{co}) are shown in Table 2. It shows that IIC could save up to 43% of water, with an average of 38%.

We have observed that classical irrigation times (at which waterfront reaches 2/3 of the bay length) were higher than that of human-guessed times to cut-off in all eight irrigation events. In other words, the termination of the water supply was arbitrary depending on the operator's assumption for the wetness of the soil profile in the root zone.

Table **2.** Percentages of water saving from estimated irrigation time (time to cut-off) over human guess decision-making.

Date of irrigation	Human Guessed Tco (min)	IIC Estimated Tco (min)	IIC Water Saving %
11-Dec-07	311	209	33
31-Jan-08	301	180	40
13-Feb-08	357	228	36
26-Feb-08	292	165	43

5. DISCUSSION AND CONCLUSIONS

In this research authors have found an important theory, which is the optimal irrigation time exists when the rate of water loss is equal to the uniform inflow rate equivalent to the maximum infiltration requirement'. The second derivative related to Equation 3 is always negative for all inflow rates, which implies a so-called maximum. The results received from the experimental irrigation events, confirm this finding, which is a major outcome for optimal irrigation requirements. In addition, authors were able to find two (Eigen) solutions numerically (from the solution-space) and given an option to chose the best fitting one.

The lower value of the range 'Water Saving Percentage' in Table 2 was 33% and the standard deviation was 4.7%. This indicates the IIC's capability to save significant amount of water, maintaining better pasture growth.

More than four hours of labour savings can be achieved if the IIC sends signals to WSN to close water supply from gate to the farm bay. A scheduler in between the WSN and the IIC can automatically capture waterfront-reaching times and pass optimal solutions to the WSN for closing the gate. The gate will open when the average minimum soil moisture threshold is reached or well before the wilting point of pasture. Encapsulating these components (by the scheduler), automates the process saving further labour cost. However, the automated controller is beyond the scope of this paper.

Water allocation in northern Victoria has been 0% following a governmental announcement made on the 1st of September 2008. Considering these issues, the IIC, can be integrated as appropriate into an automated system or manual system, which could save significant amount of water and cost of labour.

The unsupervised nature of the IIC facilitates an automated control of border-check irrigation in real time. Further investigation is underway for a development of a fully automated irrigation control.

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