

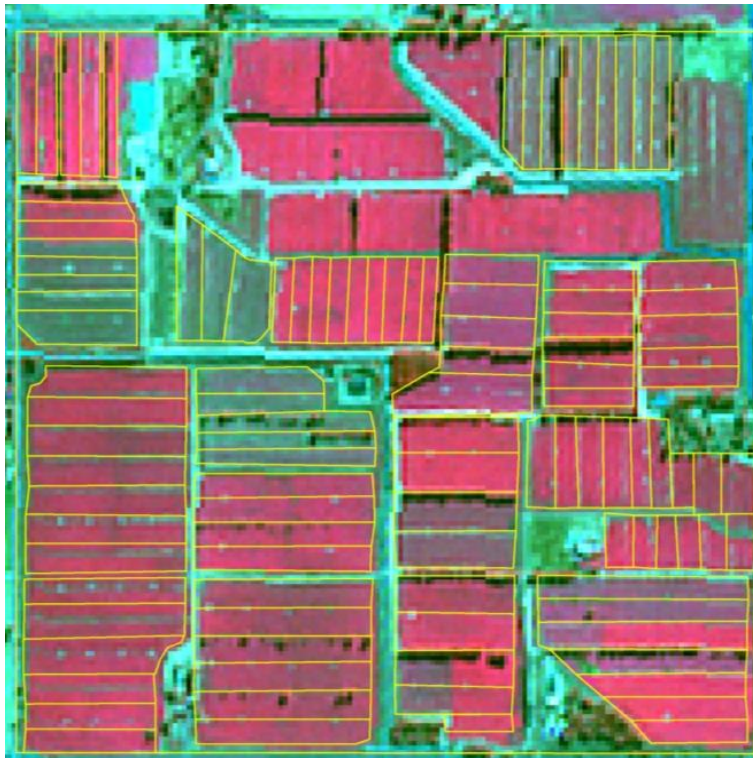
# Rural R&D for Profit Programme

Smart irrigation: when and how much  
Project 1a  
Final Report

RRDP

June 2015 - May 2018]

Andy McAllister



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### Acknowledgements

[If applicable].

# Contents

<b>Plain English summary .....</b>	<b>iv</b>
<b>Abbreviations and glossary.....</b>	<b>1</b>
<b>1 Project rationale and objectives .....</b>	<b>2</b>
<b>2 Method and project locations .....</b>	<b>3</b>
<b>3 Project achievements.....</b>	<b>5</b>
3.1 Project level achievements .....	5
3.2 Contribution to programme objectives .....	6
<b>4 Collaboration .....</b>	<b>8</b>
<b>5 Extension and adoption activities .....</b>	<b>9</b>
<b>6 Lessons learnt.....</b>	<b>10</b>
<b>7 Appendix - additional project information .....</b>	<b>11</b>
7.1 Project material and intellectual property.....	11
7.2 Equipment and assets .....	11
7.3 Media and communications material .....	11
7.4 Evaluation report.....	11
7.5 Budget.....	11

# Plain English summary

## Introduction

Economic and social concerns are driving an increased focus on water use in irrigated dairying in SE Australia. Engineering improvements in irrigation supply infrastructure have substantially increased the ability of irrigators to control both the timing and amount of water delivered to crops, and industry water saving options are focused on improving the ability of farmers to match irrigation water use to plant water requirements.

This project combines recent and forecast weather data with satellite imagery to provide local, web based crop and location specific measures of reference evapotranspiration ( $ET_{ref}$ ) and crop coefficient ( $K_c$ ) for use in irrigation scheduling. The project uses the recently developed satellite/weather based irrigation information system (SBIIS) which can determine crop water requirement at paddock scale over large areas and successfully demonstrates its ability to provide reliable and affordable automated irrigation scheduling on dairy farms in Victoria.

Irrigators require simple and affective scheduling tools that allow them to capitalise on the farm and regional irrigation infrastructure investments enabling the minimisation of water use and attendant labour and energy costs. The project was designed to provide irrigation information that affordably matches on-farm irrigation supply with crop water demand over large production areas and negates the need for irrigators to independently acquire the technical skills needed for precision irrigation practices.

The objectives of this project have been:

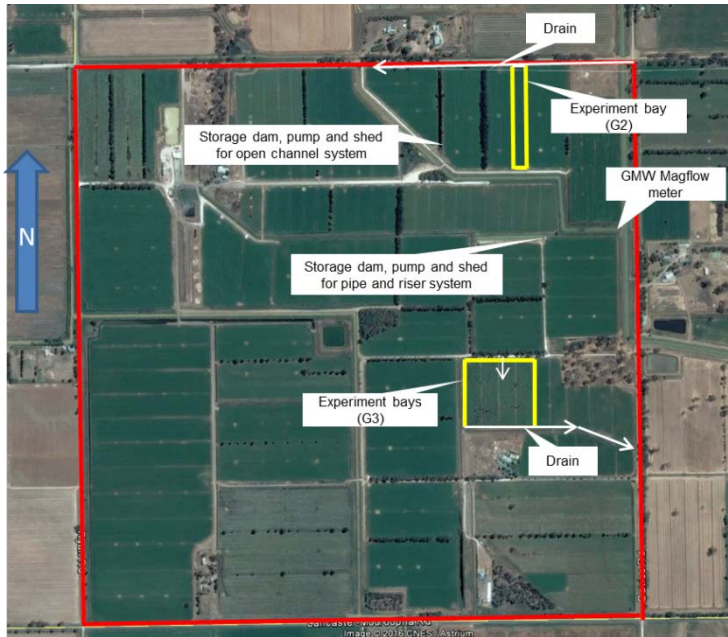
1. To develop SBIIS irrigation performance pilots to be implemented on commercial dairy farms.
2. To implement and demonstrate to irrigators and irrigation service providers automation of irrigation events triggered by SBIIS.
3. To deliver SBIIS based web service that is available to irrigation industries

## Methods

The project selected a dairy farm in Northern Victoria to undertake SBIIS irrigation performance pilots in partnership with irrigation automation service providers Rubicon. Rubicon have established irrigation automation incorporating a basic scheduling service on the property as depicted in the figure below.

This project specifically researched the performance of a satellite based approach to irrigation scheduling in surface irrigation of perennial pastures making the results applicable to the grazing based industries, particularly dairy in south eastern Australia.

The project aimed to develop and test a simple and robust irrigation scheduling system based on satellite and weather information which can be repeatable and scalable to manage large number of bays.



## Results

The project successfully achieved high application efficiencies and significantly reduced irrigation duration and volume over the period of the trial (2016/17-2017/18).

A scheduling system has been developed based on satellite imagery and weather data to estimate pasture water use, bay scale soil water deficit and the timing and duration of irrigation events.

Despite the uncertainty inherent in the estimates of crop water requirement and in the measurement of inflow and runoff, results suggest that the system has the potential to manage irrigation automation for relatively low permeable dairy soils.

## Conclusions

The outcomes of this project highlighted the need to simplify the on-farm and decision-making components that an irrigator requires to develop a robust irrigation schedule. The current complexity in irrigation scheduling equipment (i.e. soil moisture monitoring) means that irrigators need to spend time interpreting and analysing data to arrive at irrigation decisions. This is challenging when dealing with a few irrigation bays but many dairy farms may have 100 plus bays.

This presents a big challenge for irrigators when they want to scale up the water management decision making and align with farm operations such as grazing. Irrigators therefore typically will drop back to experience and how they have always operated as a default.

Satellite-based irrigation scheduling methods avoid this problem by having minimal reliance on in-field hardware, and the maintenance of costly on-farm instrumentation of the large numbers of bays that are needed on large modern dairy farms.

# Abbreviations and glossary

Provide a list of abbreviations and description of key words if used frequently throughout the report.

SBIS. Satellite/weather based irrigation information system

ETref Reference evapotranspiration

Kc Crop co-efficient.

# 1 Project rationale and objectives

In plain English, explain why the project was undertaken and how the project addresses an industry need.

Describe the project objectives including any changes to the project objectives that may have occurred over the life of the project.

Economic and social concerns are driving an increased focus on water use in irrigated dairying in SE Australia. Engineering improvements in irrigation supply infrastructure have substantially increased the ability of irrigators to control both the timing and amount of water delivered to crops, and industry water saving options are focused on improving the ability of farmers to match irrigation water use to plant water requirements.

This project combines recent and forecast weather data with satellite imagery to provide local, web based crop and location specific measures of reference evapotranspiration ( $ET_{ref}$ ) and crop coefficient ( $K_c$ ) for use in irrigation scheduling. The project uses the recently developed satellite/weather based irrigation information system (SBIIS) which can determine crop water requirement at paddock scale over large areas and demonstrates its ability to provide reliable and affordable automated irrigation scheduling on dairy farms in Victoria.

The project will allow producers to capitalise on the farm and regional irrigation infrastructure investments enabling irrigators to minimise water use and attendant labour and energy costs. The project will be designed to provide irrigation information that affordably matches on-farm irrigation supply with crop water demand over large production areas and negates the need for irrigators to independently acquire the technical skills needed for precision irrigation practices.

The objectives of this project have been:

1. To develop SBIIS irrigation performance pilots to be implemented on commercial dairy farms.
2. To implement and demonstrate to irrigators and irrigation service providers automation of irrigation events triggered by SBIIS.
3. To deliver SBIIS based web service that is available to irrigation industries

## 2 Method and project locations

Provide a brief description of how the project was carried out and if there was any change in methods over the life of the project.

Provide a list of the locations of all project activities.

Describe the locations and/or regions where the research findings are applicable. This may be represented using a map.

For example, the research activities may include a specific university and a number of demonstration farms, yet the research findings may be applicable to dairy farms across south eastern Australia.

In delivering Activity 1a the project combined current, recent and forecast weather data (BoM) with satellite imagery to provide local, multi-crop web-based crop- and location-specific measures of ETref and Kc for use in irrigation scheduling, and will test the immediate ability of the approach to support high quality practical affordable automated irrigation water management on farms in Victoria.

As part of objective 1 the project selected a dairy farm in Northern Victoria to undertake SBIIS irrigation performance pilots in partnership with irrigation automation service providers Rubicon. Rubicon have established irrigation automation incorporating a basic scheduling service on the property as depicted in the figure below.



In year 1 the project worked with the providers and dairy farmer to:

- develop an SBIIS based irrigation module that will provide scheduling information for the irrigator and the automated system.
- establish an evaluation program (field trial) of the effectiveness of the triggers in improving scheduling and production outcomes for selected bays/fields within the pilot farms.

In year 2 (2016/17) the project implemented SBIIS for an irrigation bay growing perennial pasture on the trial farm. The irrigator ran his automated irrigation system according to the scheduling recommendations of the SBIIS for the 2016/17 irrigation season. Performance measurements of the irrigation events was captured in terms of irrigation timing, duration and runoff generated. Informal feedback was sought from the irrigator as to the practicality of the scheduling recommendations in the context of farm operations.

In Year 3 (2017/18) the project modified and extended the trials to cover 2 field sites and multiple perennial pasture bays across both medium and light soil types. The undertook the same performance measurements conducted the previous year. The software components of the service were modified to incorporate the generation of scheduling recommendation for multiple bays.

This project specifically researched the performance of a satellite based approach to irrigation scheduling in surface irrigation of perennial pastures making the results applicable primarily to the grazing based dairy industries in south eastern Australia.

## 3 Project achievements

Describe key results for each component of the project. Include graphs, tables and/or images where applicable.

### 3.1 Project level achievements

The projects objectives were

- 1 To develop two SBIIS irrigation performance pilots to be implemented on commercial dairy farms
- 2 To implement and demonstrate to irrigators and irrigation service providers automation of irrigation events triggered by SBIIS
- 3 To deliver an SBIIS based web service that is available to irrigation industries by June 2018

To deliver these the project has successfully:

- developed and tested for 2 irrigation pilots a simple and robust irrigation scheduling system which can be repeatable and scalable to manage large number of bays.
- developed an irrigation automation system based on satellite imagery (NDVI) and weather data (SILO/BOM) to estimate pasture water use, bay scale soil water deficit and the timing and duration of irrigation events.
- achieved high irrigation application efficiencies on the irrigation pilots by supporting irrigation events that are geared to a consistent soil water deficit and water application.

Documentation of the outcomes of these pilots are attached in the form of technical reports in the appendix.

The developed software system is currently hosted on the FarmBuild platform at <http://52.63.122.142/farmbuild/index.html>.

The activities undertaken successfully achieved objectives 1 & 2 and demonstrated that irrigation scheduling supported by the SBIIS approach can achieve high irrigation application efficiencies and can support scaling to a larger number of bays.

While we developed a web service that is available for irrigation service providers to test (objective 3) it is not in a form that can be fully integrated into an automated irrigation system. Consequently, the next challenge for this approach to be adopted as a fully automated approach to irrigation requires the further building of confidence by both irrigators and irrigation system providers that these approaches can be managed within the context of the whole farm operations.

## 3.2 Contribution to programme objectives

### **Generating knowledge, technologies, products or processes that benefit primary producers**

The project has both demonstrated an approach and delivered tools that can support significant improvements in irrigation efficiencies by irrigated dairy farmers in an environment of increasing costs and lower availability of water. The pilot showed that irrigators can take advantage of the recent satellite technology to more precisely schedule their irrigations (timing and amount) based on plant water requirements without the need to install, operate and maintain significant in-field sensors. This is an important step in developing an automated irrigation scheduling system based on satellite information. In the pilot results are indicative of a 20% improvement in irrigation efficiencies increasing the irrigators ability to make profits through saving on water, power and labour. Components of the SBIS developed in this sub-project are available as through an open source platform (<http://52.63.122.142/farmbuild/index.html>.) to all irrigation system providers. Through working with extension staff, the dairy farmers (e.g. Dairy Australia) and the irrigation systems industry (e.g. Rubicon) the findings and benefits of this software will become more widely known and built upon.

### **Strengthening pathways to extend the results of rural R&D, including understanding the barriers to adoption**

The project has developed an improved understanding of the application of satellite/weather base scheduling and its role in farm water management through the undertaking of the pilot with a respected irrigator and his service provider Rubicon. The project has also interacted and supported irrigation extension staff in the region in delivering information on scheduling approaches. Through discussions with irrigators and extension staff the project team were able to confirm that the need to install, maintain and operate in-field sensors in order to schedule (i.e. timing and duration) and potentially automate an irrigation system can be a significant barrier to many dairy farmers. Overcoming this barrier through using a simple to use satellite based system may then allow more dairy irrigators to take advantage of water efficiencies than would occur otherwise. The project also established that an irrigation scheduling system needs to scale its application to the whole farm (e.g. 100 plus irrigation bays) and integrate with the farm operations such as grazing rotations (see Lesson's Learnt Section).

### **Establishing and fostering industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.**

Through participating in the broader Smarter Irrigation project, the researchers in this sub-project have been able to have extensive participation in workshop, conferences and events to promote and enhance research collaborations. This has included discussions on issues and findings with the researchers and collaborators in the other Smarter Irrigation sub-projects. Similarly, the team has strengthened its collaboration with the water industry through its work with Rubicon (see Collaboration Section).

### **Improve the productivity and/or profitability of businesses and/or primary industries.**

The project was able to demonstrate that the pilot participant achieved at least a 20% improvement in application efficiencies (90%) and irrigation durations. The current estimate of

Smart Irrigation: when and how much Activity 1a

dairy water use on perennial pastures is 109 GL in the summer period so a 20% saving represents 38 GL of irrigation water in Northern Victoria. This can represent up to a \$7.6m annual saving to the dairy industry through not having to access the temporary water market.

The key to achieving these savings is to design irrigation scheduling systems that are simple to implement and can be scaled to the farm and integrated with farm operations. The system developed and trialled in this project represents an approach that can be implemented without excessive amounts of on-farm monitoring technology and can be scaled down or up to the farm scale.

## 4 Collaboration

The project has established several key collaborations over the life of the project, these include:

- Rubicon Water – Rubicon provide channel supply and on farm irrigation system services to the Goulburn Murray Irrigation District (GMID). Rubicon provided access to their FarmConnect software as well as provision, installation and support of monitoring equipment in the trial bays on the farm. In addition several workshops were held with Rubicon business managers and software developers to share the learnings of the research undertaken and the future directions of Rubicons on-farm and system software development. This collaboration will continue with further activities being planned with Rubicon on the pilot farm.
- Dairy irrigator Nick Ryan – Nick Ryans dairy farm represents a highly automated irrigation system to support dairy grazing. The collaboration with the irrigator has been highly productive for the researchers and has seen Nick begin to adopt the scheduling approaches tested in this project to other parts of his farm. There is a high likelihood that this farm will start to form the basis for further research into extending the scheduling approaches to support whole farm water management.
- Agriculture Victoria irrigation extension officers – The project has developed collaborations with key irrigation officers in Victoria who currently work with farmers on adopting weather and soil moisture based approaches to irrigation scheduling. This collaboration will continue with the further development of the SBIIS and its integration into improved scheduling.

## 5 Extension and adoption activities

The following extension activities have been undertaken through the life of the project. The extension activities have exposed a range of irrigators and service providers to the benefits of climate based approaches to irrigation scheduling which will ultimately translate into further adoption of these approaches which this project has been developing.

Presentations for these forums are attached in the appendix.

- Murray Dairy Business Forum held at Nick Ryan's farm for 15 irrigators (25 May 2017)
- Agriculture Victoria dairy and irrigation extension staff – 5 attendees (31 May 2017)
- Rubicon irrigation engineers, business managers and software developers – 8 attendees (25 May 2017)
- Smarter Irrigation webinar with the Smarter irrigation dairy team. – 12 attendees - (6 September 2017)
- Farm Irrigation in a modernised system workshop - 25 attendees (29th November 2017)
- Soils Discussion Group: Irrigation Scheduling Tools - Advances and practical application - 30 attendees (8 February 18)
- Workshop with irrigator and Rubicon to discuss 17/18 results and future directions – 7 attendees (14th May 2018)
- Paper “On-farm Evaluation of Satellite Based Irrigation Automation System for Border-check Irrigation in Northern Victoria’ accepted at upcoming IAL Conference Sydney (14-17th June 2018)

## 6 Lessons learnt

The key lessons learnt as part of this project is the need to simplify the on-farm and decision-making components that an irrigator requires to develop a robust irrigation schedule. The current complexity in irrigation scheduling equipment (i.e. soil moisture monitoring) means that irrigators need to spend time interpreting and analysing data to arrive at irrigation decisions.

This presents a big challenge for irrigators when they want to scale up the water management decision making and align with farm operations such as grazing. Irrigators therefore typically will drop back to experience and how they have always operated as a default.

Satellite-based irrigation scheduling methods place minimal reliance on in-field hardware, and the maintenance of costly on-farm instrumentation of the large numbers of bays that are needed on large modern dairy farms.

Methods described in this project are therefore readily scalable to deal with whole-farm automation systems which need to be addressed before large scale adoption is achievable

The programme would benefit from less emphasis on technology and more emphasis on the farming systems, irrigator behaviour and how we move to improvements in irrigation scheduling and then what role technology will play in this.

# 7 Appendix - additional project information

## 7.1 Project material and intellectual property

This project has produced the following technical reports:

Tech report 1: Irrigation scheduling system and proposed monitoring program.



CRDC RRDP 1A  
technical report 1.pdf

Tech report 2: 2016/17 Field evaluation of satellite based irrigation automation system



CRDC RRDP 1A  
technical report 2.doc

Tech report 3: 2017/18 Field evaluation of satellite based irrigation automation system.



CRDC RRDP 1A technical report 3.pdf

## 7.2 Equipment and assets

List of all equipment or assets created or acquired during the period covered by the project.

## 7.3 Media and communications material



Irrigation  
workshop\_29.11.17.



smarter irrigation  
workshop\_05.03.18.



SBIIIS  
Presentation1\_14.5.'

## 7.4 Evaluation report

Attach the final project evaluation report.

## 7.5 Budget

A statement of funds and contributions received and spent over the life of the project.

If practical, this section may be the final financial report (section E.4 of the grant agreement), containing:

- financial statements for the receipt, holding, expenditure and commitment of the grant, including a full reconciliation against the budget in the grant agreement and statements clearly showing expenditure against the grant
- a report of the receipt of other contributions (including the grantee's contributions), or if other contributions were not received as projected, an explanation of action taken in response to this shortfall
- the interest that the grantee has earned on the grant.

If not practical to satisfy requirements for the final financial report at the time of submitting the final report, please use this section to give a statement of the budget for the life of the project and submit the final financial report within 60 days of submitting the final milestone report.

# Smart irrigation: When and How Much

*Technical Report:*

*Field evaluation of satellite based irrigation automation system*

*2017/18 Irrigation assessments*

Rural Research and  
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Economic Development,  
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**AGRICULTURE VICTORIA**

Project team: Andy McAllister, Des Whitfield, Amjed Hussain, Hayden Lewis

CRDC Project Ref: RRD1601

DEDJTR Project Ref: CMI105499

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## TABLE OF CONTENTS

<b>EXECUTIVE SUMMARY .....</b>	<b>4</b>
<b>INTRODUCTION .....</b>	<b>5</b>
<b>OBJECTIVES.....</b>	<b>ERROR! BOOKMARK NOT DEFINED.</b>
<b>METHOD .....</b>	<b>6</b>
THE EXPERIMENT SITE.....	6
CLIMATE DATA.....	7
INFLOW.....	7
RUNOFF .....	8
GROUNDWATER MEASUREMENT .....	8
DEVELOPED IRRIGATION SCHEDULING SYSTEM PROTOTYPE DESCRIPTION AND SCOPE .....	9
<b>RESULTS.....</b>	<b>13</b>
IRRIGATION ASSESSMENTS AT LOCATION 1.....	13
IRRIGATION ASSESSMENTS AT LOCATION 2.....	14
<b>CONCLUSIONS .....</b>	<b>16</b>
<b>REFERENCES .....</b>	<b>17</b>

## EXECUTIVE SUMMARY

This project combines daily weather data with satellite imagery to provide local, web based crop and location specific measures of reference evapotranspiration (ET<sub>ref</sub>) and crop coefficient (K<sub>c</sub>) for the use in irrigation scheduling. The project uses recently developed satellite/weather based irrigation information system (SBIIS) which determines crop water requirement at paddock scale and demonstrates its ability to provide reliable and affordable automated border irrigation scheduling on dairy farms in northern Victoria.

This technical report presents results of the irrigation assessments completed in 2017/18 irrigation season that aims toward the implementation of SBIIS on dairy farms in northern Victoria. This report is a deliverable of the project Smart irrigation: when and how much, funded by the Commonwealth Rural Research and Development for Profit Program.

Two field experiments (L1 & L2) were conducted on a commercial dairy farm near Kyabram, Victoria. At the first location (L1) on the farm, irrigation measurements were taken on four adjacent bays including the bay that was assessed during 2016/17 irrigation season. At the second location (L2), irrigation measurements were taken on one bay with three shallow drains at approximately equal distance across the bay, these drained the last 50m of the bay. The soil type at L1 was Lemnos loam, featuring loam topsoil with a rapid change in texture at approximately 20 cm depth to relatively impermeable clay subsoil which cracked when dry. The soil type at L2 was Shepparton fine sandy loam, a relatively light texture levee soil. Both locations on the farm had an established perennial pasture, grazed by cows. The experiment bays at L1 were irrigated with a pipe and riser irrigation system while the experiment bay at L2 was irrigated by an open channel irrigation system.

SBIIS was used to predict the date of the next irrigation using a crop water requirement of approximately 50 mm. At both locations, extra water was added to the crop requirement to ensure that water reached the end of the bay. A simple volume balance method was used to calculate irrigation inflow duration. The cumulative runoff of four bays was measured at L1, while runoff was also measured at L2.

Over the four pasture irrigations measured at L1 an average of 48.1 mm water was applied in each irrigation on each bay to satisfy a 46.7 mm crop water requirement with 2.3 mm runoff. The average runoff was approximately 4.8% of applied water.

Over the four pasture irrigations measured at L2 an average 78.7 mm was applied in each irrigation to satisfy 48.5 mm crop requirement. Runoff occurred in all irrigations and ranged between 33.8 mm in the first irrigation and 11.2 mm in the fourth irrigation. However, water did not reach the end of the bay in the fourth irrigation and drained through the shallow drains. The average runoff accounted for 31% of applied water. More runoff at L2 was unavoidable because of shallow drains and the reduction of applied water on a light soil will not guarantee that water will reach the bay end.

Despite the uncertainty inherent in the estimates of crop water requirement and in irrigation measurements, the results of the preliminary field experiments suggest that the system has the potential to significantly improve the management of border irrigation automation in northern Victoria.

## **INTRODUCTION**

Economic and social concerns are driving an increased focus on water use in irrigated dairying in south-eastern Australia. Engineering improvements in irrigation supply infrastructure have substantially increased the ability of irrigators to control both the timing and amount of water delivered to crops and industry water saving options are focused on improving the ability of farmers to match irrigation water use to plant water requirements.

This project combines daily weather data with satellite imagery to provide local, web based crop and location specific measures of reference evapotranspiration (ET<sub>ref</sub>) and crop coefficient (K<sub>c</sub>) for use in irrigation scheduling. The project uses the recently developed satellite/weather based irrigation information system (SBIIS) which can determine crop water requirement at paddock scale over large areas and demonstrates its ability to provide reliable and affordable automated irrigation scheduling on dairy farms in northern Victoria.

The project will allow producers to capitalise on the farm and regional irrigation infrastructure investments enabling irrigators to minimise water use and attendant labour and energy costs. The project is designed to provide irrigation information that affordably matches on-farm irrigation supply with crop water demand over large production areas and negates the need for irrigators to independently acquire the technical skills needed for precision irrigation practices.

### **Outcome**

Irrigators will have a new cost effective system available that has been demonstrated to reliably and efficiently automate irrigation scheduling and improve the efficiency of border-check irrigation.

### **Objectives:**

1. To develop SBIIS irrigation performance pilots to be implemented on commercial dairy farms.
2. To implement and demonstrate to irrigators and irrigation service providers automation of irrigation events triggered by SBIIS.
3. To deliver SBIIS based web service that is available to irrigation industries.

This technical report pertains to the project objective 2 and presents results of the irrigation assessments taken in 2017/18 irrigation season.

## METHOD

### *The experiment site*

Two field experiments were conducted on a commercial dairy farm near Kyabram in the Goulburn Murray Irrigation District (GMID). At the first location (referred to as L1 in this report, see Figure 1), irrigation measurements were taken on four adjacent bays including the bay which was assessed during 2016/17 irrigation season. At the second location (referred to as L2 in this report, see Figure 1), irrigation measurements were taken on one bay.

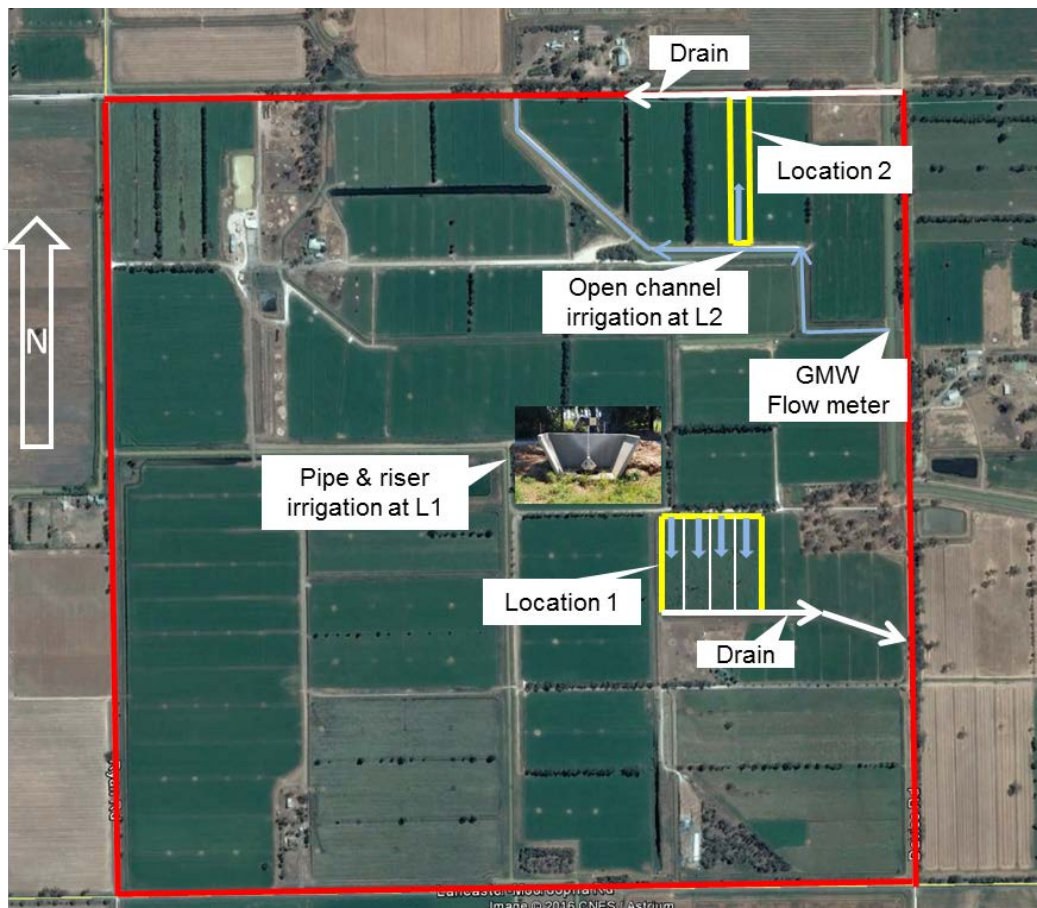


Figure 1: Location of the experiment bays at the trial site

The soil type at L1 was a Lemnos loam that featured a loam topsoil with a rapid change in texture at approximately 20 cm depth to a relatively impermeable clay subsoil which cracked when dry (Skene and Poutsma 1962). Soil type at L2 was Shepparton fine sandy loam, a relatively light texture soil, a typical soil of the levees of the prior stream sequence (Skene and Poutsma 1962).

The bays at L1 were irrigated by a pipe and riser irrigation system (Figure 2) while the bay at L2 was irrigated by an open channel irrigation system (Figure 3a). At L2, the bay had three shallow drains (Figure 3b) at approximately equal distance across the bay, these drained the last 50m of the bay. At both locations, automatic irrigation systems installed by Rubicon Water (<http://www.rubiconwater.com>) irrigated the bays. The experimental bays at both locations had an established perennial pasture, grazed by cows.



Figure 2: Irrigation in progress on one of the experiment bays at L1



Figure 3: At L2, (a) irrigation in progress and (b) shallow drains in the bay

### ***Climate data***

Daily evapotranspiration (ET<sub>o</sub>) and rainfall data were required to estimate crop water requirement using SBIIS. Rainfall and ET<sub>o</sub> data were acquired from SILO (<https://legacy.longpaddock.qld.gov.au/silo/>) weather station at Kyabram, Victoria, which was approximately 10 km west of the experimental site.

### ***Inflow***

At L1, pipe and riser irrigation system pumped approximately 14.0 ML/d inflow from an on-farm storage dam to irrigate the experimental bays. Therefore a 14.0 ML/d inflow rate was used for all irrigations at L1. At L2, irrigation water was supplied through a GMW mag flow meter, which had approximately 10.0 ML/d inflow rate. Therefore a 10.0 ML/d inflow rate was used for all irrigations at L2. The inflow data acquired later from GMW confirmed that the inflow rate at L2 was approximately 10.0 ML/d.

Fluctuations in the farm channel water level could substantially affect the inflow to the bay. Therefore, to measure the channel water level, WT-HR logging depth meters were deployed in the farm channel. Channel length was measured from satellite imagery and a tape measure was used to measure channel cross section. Change in channel water storage was calculated and subtracted from the inflow data.

## **Runoff**

Runoff was measured at both locations to evaluate irrigation performance. At L1, cumulative runoff was measured by using an ISCO flow meter (<http://www.teledyneisco.com>) fitted in a trapezoidal metal frame and installed in the drain after the fourth experiment bay (Figure 4). At L2, runoff was measured by blocking the end of the bay with dirt (Figure 5a) and converging water through the Broad Crested Weir Flumes (Clemmens et al. 2011) installed at the bay end in each shallow drain (Figure 5b). Water depth within each flume was measured by WT-HR logging depth meters and converted to inflow rate by using depth-discharge relationship.



Figure 4: Measurement of runoff at L1

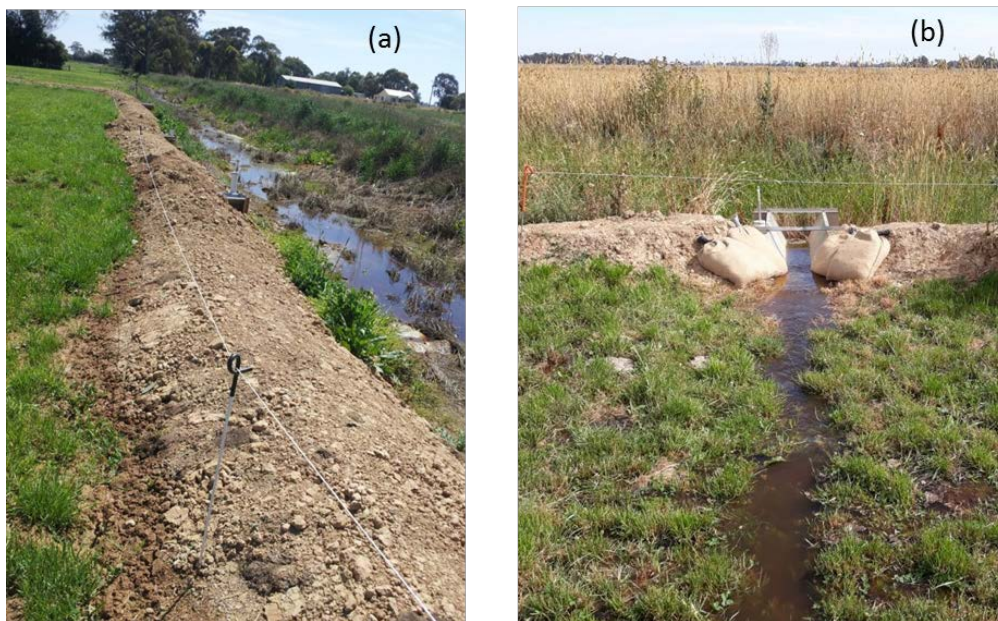


Figure 5: Measurement of runoff at L2 by (a) blocking the end of the bay with dirt and (b) converging runoff through the flume

## **Groundwater measurement**

A test well was installed at L1 and L2 and watertable was monitored occasionally by using a test well whistle. Groundwater measurements were limited to assess the presence of watertable within a test well depth of 2.2 m.

### ***Developed irrigation scheduling system prototype description and scope***

The developed SBIIS prototype computes a predicted date of next irrigation based on crop type and condition, default soil type and irrigation type, prevailing weather and recent rain (Figure 6). The prototype was developed to demonstrate the principles and application of satellite and weather based irrigation demand scheduling tool to irrigation managers in Victoria. The application scope was restricted to irrigators who seek to maintain crops in a well-watered, non-stressed state, throughout the irrigation season. Consequently, while this project focussed on perennial pastures, the crop options within the prototype also include almond, grapes, citrus, apple, peach, apricot, and other orchard crops, consistent with the expectation that crops require irrigation at least once every 10-14 days. Prototype irrigation schedules were therefore devised on the basis that crops were irrigated or heavy rain was received within the previous 10 days.

The prototype, as depicted in the workflow in Figure 6, provides site and time-specific crop and weather data for the formulation of optimal irrigation schedules for use by irrigators. Time and crop-specific satellite data are accessed to describe crop vegetation status (Normalised Difference Vegetation Index (NDVI)), and to derive appropriate values of the crop coefficient (Kc), based on pre-established, crop-type dependent relationships that describe the dependence of Kc on NDVI. The prototype provides user access to a map of NDVI for crops grown in GMID in February 2015. The client interacts with the satellite image/map provided to identify the site and extent of a client-designated field. The prototype is thereby able to retrieve the mean NDVI value for a crop and the geographic coordinates of the field. Geo coordinates are used to identify the nearest SILO weather station (SILO\_ID). SILO rainfall data recorded at the nearest AWS in the past 10 days are retrieved and presented to the client, who is then able to modify the rainfall data with locally-measured farm specific values in order to use site-specific rainfall data in preference to the default SILO rainfall data that are used in calculations of the irrigation soil water balance.

The client is also required to provide information concerning crop type (perennial pasture, almond, grapes, citrus, apple, peach, apricot, other orchard) and soil type (heavy, medium, light). The interaction of the client with the prototype user interface results in the submission of crop-specific values of crop type (CropType), soil type (SoilType), crop location (geographic coordinates of the field), crop vegetation status (NDVI), and the site of the nearest SILO weather station (SILO\_ID) that provides the most appropriate measures of the (local) weather variables needed for the calculation of local evaporative demand (REFET; based on SILO temperature data, SILO solar radiation, and SILO vapour pressure data for the 10 days immediately preceding the prototype request). The user also enters the data of the last irrigation in the form YYYY-MM-DD.

User information is sent to the server in the form of a compound string variable, including data entries for NDVI, recent rainfall (preceding 10 days; optional), Soil Type, Crop Type, Date of Last Irrigation, SILO\_ID is submitted via a “master” Python script enables the data to be passed to a server-based R program for processing.

### **Prototype irrigation scheduling application data integration and modelling**

As described above the prototype allows users to interact with the scene to identify crop/field, to modify the local rainfall data provided by SILO, and to enter a value for the date of last irrigation, in order to derive a predicted date of next irrigation for the crop.

Weather-based irrigation scheduling relies on district-specific estimates of reference evapotranspiration (ET<sub>ref</sub>) acquired from local weather stations. The irrigation scheduling application sources weather data from SILO ([www.longpaddock.qld.gov.au](http://www.longpaddock.qld.gov.au)) in the form of daily weather data (sourced from Bureau of Meteorology (BoM)) suited to the calculation of “tall” and “short” versions of ET<sub>ref</sub> applicable to lucerne and short green grass, (ET<sub>r</sub> and ET<sub>o</sub>, respectively; Allen et al 2006). SILO provides daily ‘patched

point' data, suited to daily ETref calculations for approximately 600 stations which provides a comprehensive spatial coverage of Victoria. Data are available on a daily basis, up to and including the day prior to download (i.e. 'yesterday'). The application downloads weather data for all Victorian weather stations covering a 10-day window that spans the period up to and including 'yesterday'. SILO data downloads are conducted in the early hours of the morning to make district-specific ETref and rainfall information available to users. R scripts are used to:

1. download SILO data
2. calculate daily measures of ETo and ETr for use in irrigation scheduling calculations: ETr provides values of ETref appropriate to orchard, vine and nut crops in northern Victoria, and ETo provides the values of ETref appropriate to pastures and short crops. District-specific ETref and rainfall data will be stored for later use in the irrigation scheduling application.

The prototype satellite-derived NDVI data is initially generating schedules based on Landsat 8 images acquired for the Shepparton region.

### **Irrigation scheduling recommendations**

Irrigation scheduling recommendations provided by the prototype provide a simple estimate of the predicted date of next irrigation, based on crop type, date of last irrigation and rainfall information provided by the user. Computations were performed by an R language script that uses Agriculture Victoria Research Tatura ET-NDVI relationships to estimate crop-specific values of the crop coefficient (DPI 2011) and derived measures of ETo and ETr to estimate crop ET (ETc) in the period from the date of last irrigation. The date of last irrigation is assumed to be 11 days ago if the irrigation date is not nominated by the client-user interface, and mean rates of ETref over the 10-day scheduling window are assumed to prevail in rain-free conditions to predict future values of the date of next irrigation. In cases where the date of next irrigation falls in the past, the value of the date of next irrigation will be reported as "today".

Note that the accuracy of predictions of the date of next irrigation will become increasingly certain as the actual date approaches the predicted date of next irrigation because of the inclusion of actual rather than predicted values of ETref and rainfall.

### **Frequency of irrigation**

At each location, irrigation will be applied at evapotranspiration minus rainfall (ETc-R) equal to approximately 50 mm, estimated by irrigation scheduling application outlined above.

### **Duration of inflow**

Different approaches can be used to cutoff inflow onto the bay. These approaches include irrigator's experience, real-time automation by using water sensor system, and a simple volume balance method (bucket method). In this work a simple volume balance method (Grismer and Tod 1994; Martin 2006) was used to calculate inflow duration.

$$T = (14.4AD)/Q \quad \text{Equation 1}$$

Where T is inflow duration (minutes), A is area of the bay (ha), D is water applied (mm), and Q is inflow rate (ML/d).

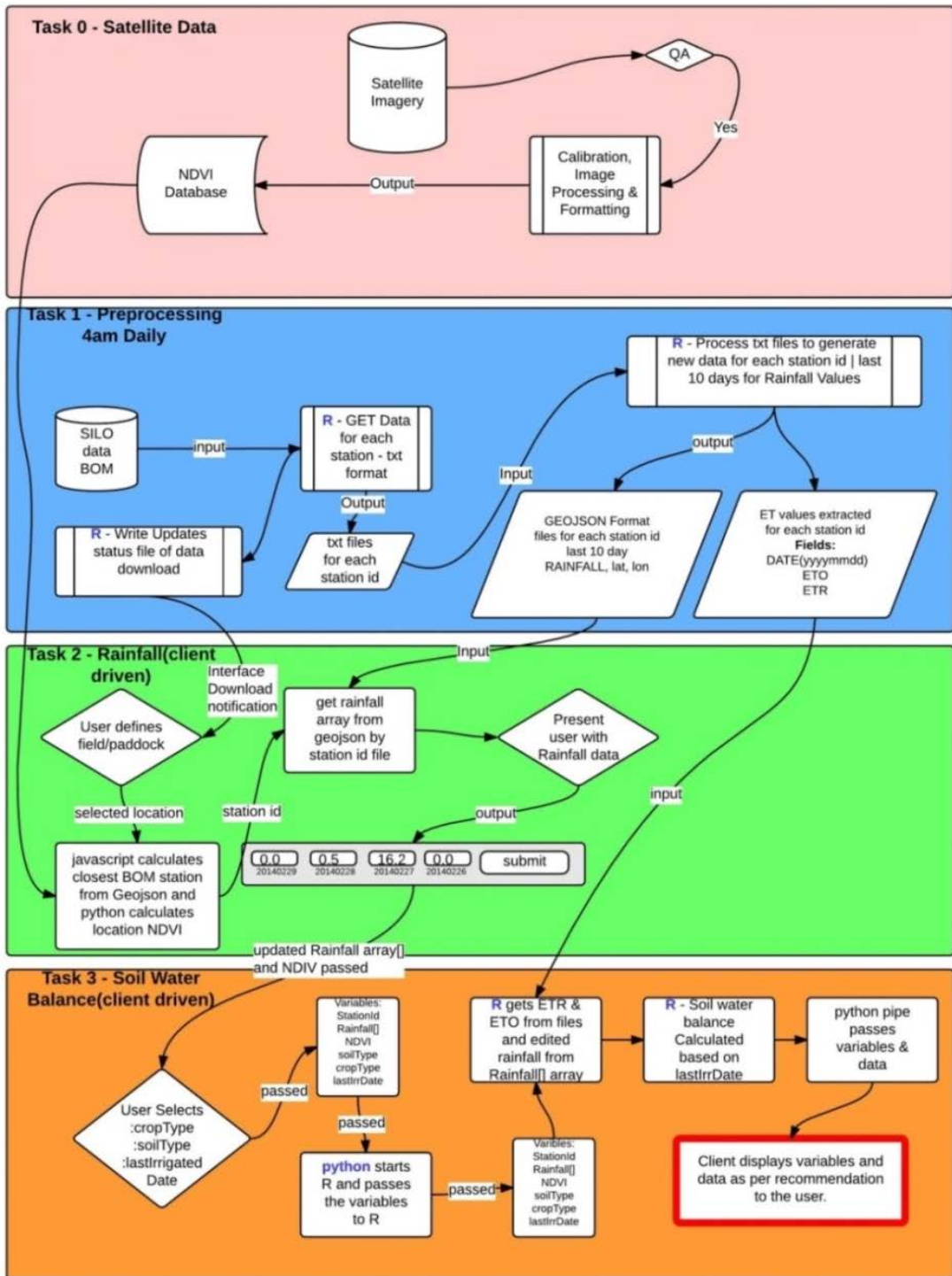


Figure 6: Irrigation scheduling application

### ***Irrigation scheduling procedure***

A block diagram of the irrigation scheduling process tested on both locations on the farm is shown in Figure 7 and detail is provided below.

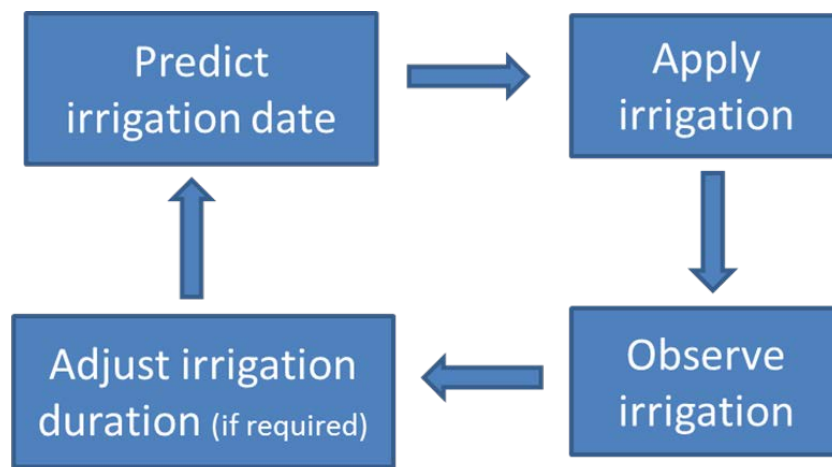


Figure 7: Block diagram of the irrigation scheduling process

1. Predict the date of the next irrigation for crop water requirement (ETc-R) equal to approximately 50 mm.
2. Send an SMS to the irrigator before the irrigation date. Irrigation date or inflow duration will be adjusted if rainfall occurs before the irrigation date. Irrigation duration will also be adjusted if the farmer decides to irrigate on a different date than the predicted date.
3. At the start of the irrigation season, irrigate the bay for a time which farmer generally uses for irrigations. Observe the irrigation and measure runoff.
4. Based on a number of initial irrigation assessments (Step 3), add additional water to the crop water requirement to ensure the water reaches the end of the bay.
5. Use Equation 1 to calculate the inflow duration.
6. Irrigate the experiment bay for the calculated inflow duration.
7. Observe the irrigation and measure runoff.
8. In the next irrigation, adjust the additional water and irrigation duration, if required.

## RESULTS

### *Irrigation assessments at location 1 (L1) for 2017/18*

The bays were approximately 48 m wide and 200 m long. At this location, a watertable was found within 2.0 m from the bay surface. Four irrigations were measured at this site. An example of the predicted date of one of the measured irrigations is shown in Figure 8. In this figure, the y-axis is available soil water (asw), ws80091 is the SILO code for Kyabram weather station, and the vertical dotted red line is the date model ran to predict the next irrigation date.

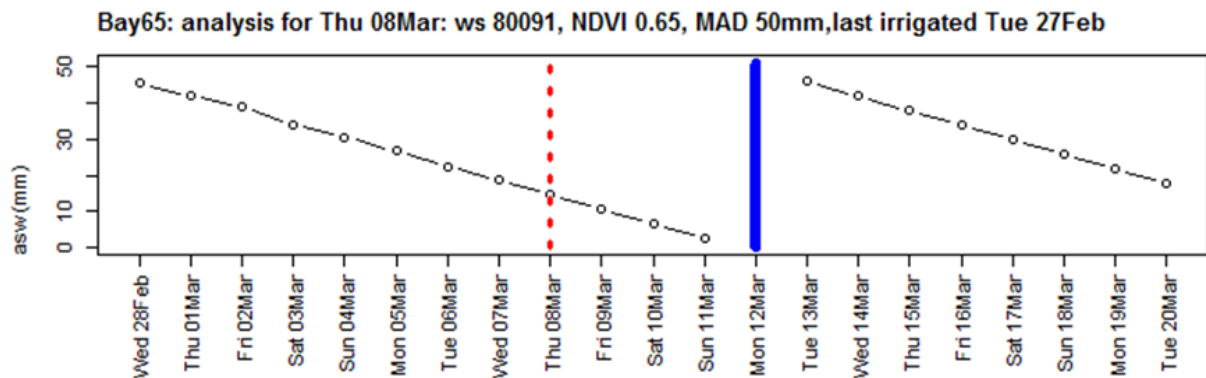


Figure 8: Predicted date of the fourth irrigation at L1

In each irrigation, approximately 3 mm water was added to the crop water requirement of each bay to ensure that water reached the end of the bays. Over the four irrigations, average water applied on each bay ranged from 45 mm to 50 mm to satisfy a 46 to 48 mm crop water requirement (Figure 9). At this site there is likely to be some losses due to deep drainage however this component has not been quantified.

The average runoff of each bay is presented in Figure 9 and is based on cumulative runoff of four bays. The average runoff ranged between 1.0 to 3.5 mm. In the first irrigation, runoff occurred only on one bay because inflow duration was four minutes less than the inflow time calculated by the volume balance method. In the irrigations two to four, inflow time for each bay was approximately same as calculated by volume balance method. Although water reached the end of all bays in the second irrigation, runoff occurred only on two bays because extra water was not added to satisfy the crop requirement of the dry area left at the end of the bays in the first irrigation. Runoff occurred on all bays in the last two irrigations. The average runoff of four irrigations was 4.8% of applied water.

The 2016/17 and 2017/18 results have consistently demonstrated application efficiencies of over 90%.

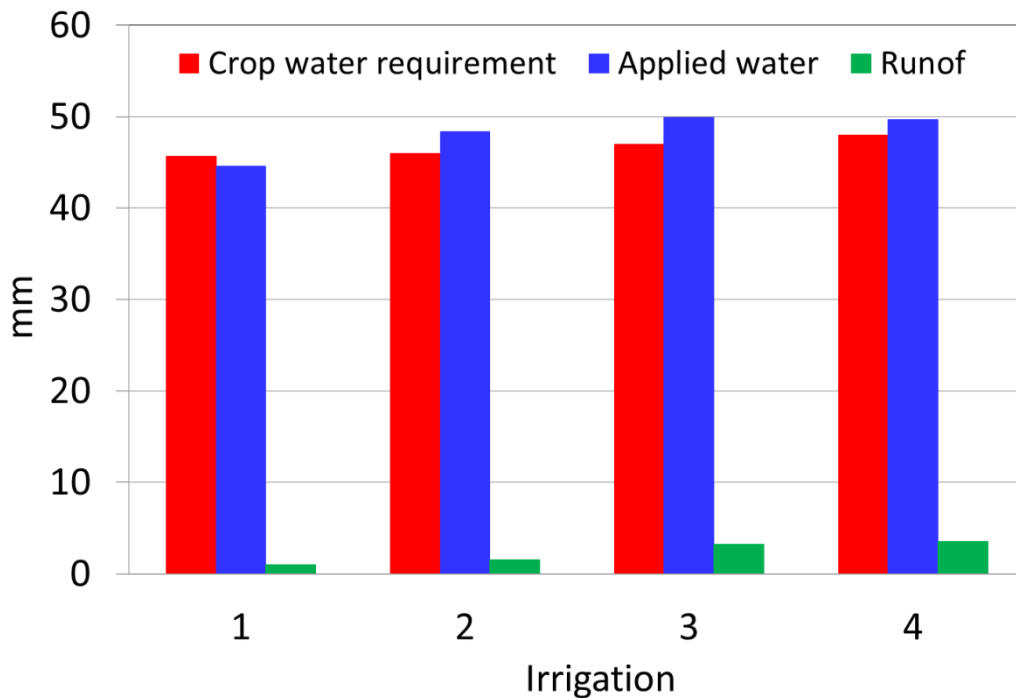


Figure 9: Average crop water requirement, applied water and runoff of each bay at L1

***Irrigation assessments at location 2 (L2) for 2017/18***

The experiment bay at L2 was approximately 38 m wide and 300 m long. The contribution, due to channel fluctuations, to variability in any irrigation event was less than 5% of applied water. Over the four irrigations measured at this location, 67 to 89 mm water was applied to satisfy a 47 to 50 mm crop water requirement (Figure 10).

Runoff occurred in all irrigations and ranged between 33.8 mm in the first irrigation and 11.2 mm in the fourth irrigation (Figure 10). The average runoff of four irrigations was 31% of applied water. At this location, it was assessed that approximately 30 mm extra water was required to ensure that water reached the end of the bay. We attempted to reduce irrigation application losses to 20 mm in fourth irrigation but this resulted in water only reaching approximately 285 m down the bay. However, 11 mm runoff still occurred in this irrigation because of surface drainage through the shallow drains. At this location, deep drainage (applied depth – crop water requirement – runoff) was less than the L1 site could be due to the higher watertable found within 1.5 from the bay surface.

It should also be noted that while application efficiency was low (56%-66%) over the period of the 4 irrigations applied water and runoff was reduced by over 24% and 40% respectively a large improvement in the outcome of the irrigation event.

While application efficiency may be improved with better management of the deficit and duration of the irrigation event the physical limitations of the bay in regards to soils type and shallow drains means application efficiency will always be lower than L1.

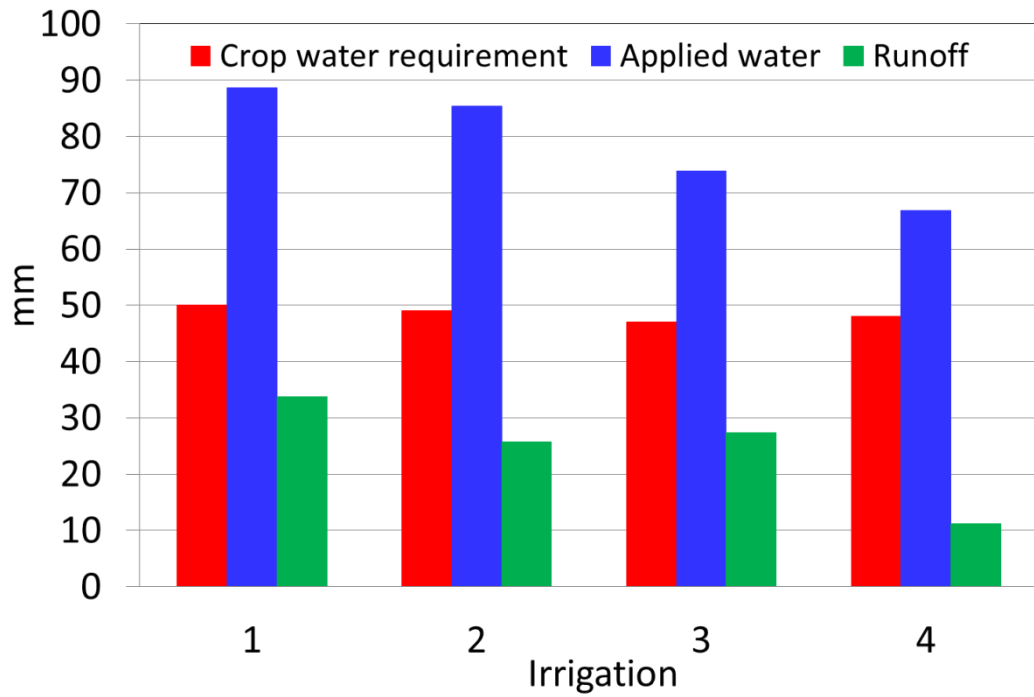


Figure 10: Crop water requirement, applied water and runoff of the bay at L2.

## **CONCLUSIONS**

The results of the field experiments in 2016/7 suggested that the SBIIS support successful irrigation events and has the potential to manage irrigation automation of a large number of bays.

The 2017/18 results further reinforce this finding with high application efficiencies (>90%) measured for the L1 site across both seasons and across multiple bays.

At the L2 site while application efficiency was low (56%-66%), over the period of the 4 irrigations applied water and runoff was reduced by over 16% and 24% respectively a large improvement in the outcome of the irrigation events.

These results demonstrate that the satellite/weather based triggering of irrigation dates combined with a simple volume balance method for irrigation duration and flow can support successful irrigation events with high application efficiencies.

More importantly there is a minimal need for instrumentation to support this system with the main requirements being on limited observation/measurement of runoff events to provide a check/calibration that the system is working.

The other main requirement is that a farm is able to maintain consistent depths in channel supply systems and knowledge of pump or G-MW supply flow rates. This was the case on the farm studied (<5%).

Therefore a precise and repeatable irrigation behaviour can be achieved in border irrigation when irrigation events triggered by the SBIIS are geared to consistent soil deficit and irrigation application. The minimal need for bay-scale instrumentation offers the potential for an affordable control of irrigation automation of multiple bays.

### ***Lessons learned from the field evaluation of SBIIS***

- Observation of bays during and after the irrigation event is important to evaluate irrigation performance and to adjust inflow duration in the next irrigation if required.
- Farmer's feedback is important during irrigation scheduling.
- It is convenient for the farmer if the inflow duration provided is rounded to the nearest 5 minutes (e.g. 45, 50, 55 minutes).
- Farmer feedback indicated that the predicted date of irrigation by SBIIS is sometimes one to two days later than the farmer would have estimated.
- Farmer exposure and interest in satellite and weather based irrigation scheduling has increased over the period of the study.
- The model needs to incorporate a secondary source of weather information as SILO data was sometimes not available.

### ***Further questions to be investigated***

- Is SBIIS practicable and scalable at the farm scale?
- If scaling can be achieved can we align irrigation and grazing schedules together?
- A combination of limited hardware measurement systems and robust software is required to automate and implement SBIIS at the farm scale.

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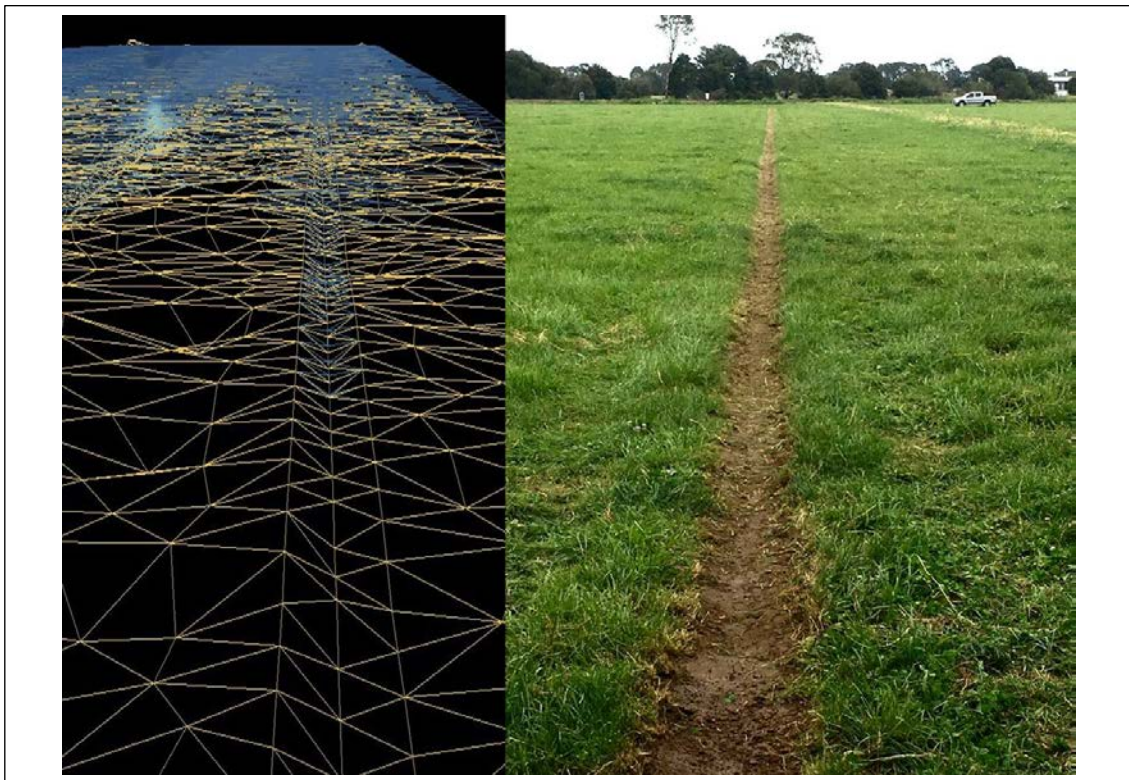
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# Rural R&D for Profit Programme

Smart irrigation: when and how much,  
Activity 2c  
Final Report

July 2015 to June 2018

Mike Morris



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### Acknowledgements

[If applicable].

# Contents

<b>Plain English summary .....</b>	<b>iv</b>
<b>Abbreviations and glossary.....</b>	<b>Error! Bookmark not defined.</b>
<b>1 Project rationale and objectives .....</b>	<b>1</b>
<b>2 Method and project locations .....</b>	<b>2</b>
<b>3 Project achievements.....</b>	<b>3</b>
3.1 Project level achievements .....	3
3.2 Contribution to programme objectives .....	3
<b>4 Collaboration .....</b>	<b>5</b>
<b>5 Extension and adoption activities .....</b>	<b>6</b>
<b>6 Lessons learnt.....</b>	<b>7</b>
<b>7 Appendix - additional project information .....</b>	<b>8</b>
7.1 Project material and intellectual property.....	8
7.2 Equipment and assets.....	8
7.3 Media and communications material .....	8
7.4 Evaluation report.....	9
7.5 Budget.....	9

# Plain English summary

Border-check is a surface irrigation practice used by over 90% of irrigated dairy farms in the southern Murray Darling Basin. Laser guided landforming machinery is used to grade land to a smooth slope generally from 200 to 1000 m long with an elevation gradient of between 1 in 200 and 1 in 1000. Low check banks are then formed down the slope to create bays that are usually between 40 and 80 m wide. Irrigation water is released at the top of each bay from a supply channel, with a drain at the foot of the bays directing excess surface water to a re-use dam.

Conventional border-check irrigations on sites with low permeability soil profiles are inherently non-uniform because drainage of excess surface water from bays is very much slower than the process of applying the water. Water can be applied relatively quickly with modern irrigation supply systems, but once the supply is cut off energy rapidly dissipates, leaving excess surface water to slowly find its way down the length of irrigation bays in a process that can take days to complete.

This project established a field experiment and demonstration site in the Macalister Irrigation District (MID) of Victoria that aimed to show higher irrigation performance through modification of irrigation bay surfaces to improve surface water drainage. The field experiment and demonstration site consisted of four adjacent border-check irrigation bays producing perennial ryegrass pasture grazed by dairy cows. The surfaces of two randomly selected irrigation bays were modified to reduce the duration of surface water ponding after irrigations and reduce variation of ponding duration within each bay.

Six irrigations on the four bays were measured during the 2016/17 and 2017/18 irrigation seasons, however accurate scheduling of irrigations proved to be infeasible using the non-modernised and manually operated farm irrigation system. The resulting variability in irrigation applications reduced the value of direct comparisons between the conventional and modernised irrigation bays.

The experiment was able to demonstrate the effectiveness of the modified bay surface in draining excess surface water rapidly after irrigations. Pasture consumption varied between irrigation bays and between seasons, but exhibited no consistent difference between the conventional and modified bay surface treatments. Similarly, there was no difference in the observed pugging damage by cows between the bay surface treatments.

The work at this site has highlighted that realising the full potential of the modified bay surface requires an irrigation supply system with the capability to deliver consistent, precise irrigations to each bay. While the modified bay surface can improve the performance of any bay that ponds excess surface water, it should be implemented as one component of an efficient, modernised and automated surface irrigation system.

# 1 Project rationale and objectives

The large investment made by Governments and irrigators in the past decade to improve district and farm irrigation delivery systems provides the opportunity for more precise irrigations that meet plant water requirements. However conventional irrigation bays commonly limit this opportunity because they inherently deliver non-uniform irrigations.

The objective of this project activity was to demonstrate to border-check irrigators and irrigation service providers in the Macalister Irrigation District of Victoria the benefits of an improved irrigation bay surface that reduces the duration and variation of surface water ponding within border-check bays after irrigations.

Reducing the duration and the variability of duration of water ponding after border-check irrigations will deliver greater uniformity of surface irrigations and thereby enable precision scheduling of border-check irrigations.

## 2 Method and project locations

The project used a modified 2D ANUGA surface water flow model to identify a bay surface modification that substantially reduced surface water ponding duration and reduced the variation in ponding duration within irrigation bays after irrigations. A wide range of prospective bay surface designs was evaluated. The stand-out performer with respect to simulated hydraulic performance and robustness under a wide range of conditions was also straightforward to implement.

Field demonstration of the modified bay surface involved four adjacent perennial ryegrass pasture bays located on a commercial dairy farm in the Macalister Irrigation District of Victoria. Two randomly selected bays had the modified surface installed, while the other two bays retained a conventional bay surface. The simplicity of the bay modification allowed us to have the demonstration site established in October 2016. All irrigation bays were managed by the farmer.

Assessment of the irrigation performance and productivity of each of the four bays has been undertaken since October 2016. During this period the modified bays have been hydraulically assessed in the field against the conventional bays and against model predictions by capturing inflow hydrograph, runoff hydrograph and surface ponding duration on each bay. Pasture production has also been monitored on all bays.

This project focused on improved border check bay (i.e. flood irrigation) design. The results are applicable to industries that use this method of irrigation with shallow rooted crops on soil profiles that have a slow final infiltration rate. The use of the modified 2D ANUGA model to simulate potentially more efficient irrigation designs would be applicable to other surface irrigation systems.

## 3 Project achievements

### 3.1 Project level achievements

The project has established a field experiment and demonstration site in the Macalister Irrigation District (MID) of Victoria that has attempted to show higher irrigation performance through modification of irrigation bay surfaces to improve surface drainage. The field experiment and demonstration site consisted of four border-check irrigation bays producing perennial ryegrass pasture grazed by dairy cows. The surfaces of two randomly selected irrigation bays were modified to reduce the duration of surface water ponding after irrigations and reduce variation of ponding duration within each bay.

Six irrigations on the four bays were measured during the 2016/17 and 2017/18 irrigation seasons. Accurate scheduling of irrigations proved to be infeasible using the non-modernised and manually operated farm irrigation system. The high variability in irrigation applications reduced the value of direct comparisons between the conventional and modernised irrigation bays.

The experiment was able to demonstrate the effectiveness of the modified bay surface in draining excess surface water rapidly after irrigations. Pasture consumption varied between irrigation bays and between seasons, but exhibited no consistent difference between the conventional and modified bay surface treatments. Similarly, there was no difference in the observed pugging damage between the bay surface treatments.

While the experiment was able to demonstrate greater irrigation uniformity and reduced durations surface water ponding on the modified bays, the work at this site has highlighted that realising the full potential of the modified bay surface requires an irrigation supply system with the capability to deliver consistent, precise irrigations to each bay. While the modified bay surface can improve the performance of any bay that ponds excess surface water, it must be implemented as part of a well managed, modernised and automated surface irrigation system to achieve its potential.

### 3.2 Contribution to programme objectives

Over 90% of irrigated dairy farms in the southern Murray-Darling Basin use border-check systems. Similarly, it is the most common irrigation system in the Macalister Irrigation District in southern Victoria. It is very commonly used on sites that have elevation gradients of less than 1 in 250 and soils that have relatively low permeability. Border-check systems do have a shortcoming, though, particularly on these relatively flat sites with low permeability soil profiles.

The problem arises because drainage of excess surface water from bays is very much slower than the process of applying the water. Excess surface water at the top of bays must find its way

to a drain by flowing across the entire downslope surface of the bay in a process that can take days to complete.

Modernised irrigation supply systems provide substantially higher, more uniform and more accurately measured irrigation flow rates that can be ordered and delivered at much shorter notice. For the first time in regulated irrigation areas, irrigators have the opportunity to more precisely schedule irrigations to better meet plant water need. At the same time, new and improved systems for irrigation scheduling continue to appear and are the focus of active ongoing research, development and extension.

A limiting factor for precision scheduling of border-check systems is the non-uniformity of the conventional irrigation bay itself. An optimal schedule for the top of a conventional bay will favour unproductive swamp plants at the bottom of the bay, while optimising for the bottom will cause regular periods of water stress at the top.

By modifying bay surfaces with very shallow surface drains, all areas of the bay receive a similar irrigation and experience shorter durations of surface water ponding. An irrigation schedule for a modified bay can be optimized and will be optimal for the whole bay.

Irrigators using modified bays believe they have consistently high pasture production across the whole irrigated area. Because ponding duration is reduced there is also less deep drainage below the rootzone which saves water and reduces the environmental footprint of irrigation.

## 4 Collaboration

The project has facilitated improved links within Agriculture Victoria between surface irrigation research centred in northern Victoria and irrigation extension services located in Gippsland. Collaboration has been established with irrigation extension staff based in the Maffra office who have provided local monitoring data acquisition and oversight of the project demonstration site.

Prior to conclusion of the project, the demonstration site established under this project will be relocated to the Macalister Demonstration Farm. This will support integration of this project with the activities of the Rural Research and Development for Profit Programme (RRDPP) Smart Irrigation “Optimised Dairy Irrigation Farms” project and will facilitate ongoing collaboration across Agriculture Victoria and the dairy industry in the Macalister Irrigation District.

Increased discussion and engagement with fellow researchers in other states and other agricultural industries has improved the exchange of water use efficiency ideas and issues. This is likely to develop further in any further national irrigation projects

## 5 Extension and adoption activities

As described under Section 4, the demonstration site established under this project will be relocated to the Macalister Demonstration Farm (MDF), integrating it with the complementary activities there. A factsheet, technical note and video have been prepared to support ongoing extension of the project findings at the MDF. This will ensure the continued exposure of the project findings to irrigators, particularly in the Gippsland region. This ongoing demonstration, combined with the ability to present the empirical evidence from this project on the improved drainage efficiency of modified bays, will provide irrigators and irrigation service providers with the confidence to adopt these modifications appropriately.

A presentation at the Irrigation Australia Conference and Exhibition in Sydney in June 2018 will promote the project findings nationally.

The following lists the project extension activities:

### **Presentations:**

Two presentations on the project background and aims have been made to farmers and service providers at Maffra. Attendance at each was approximately 12.

### **Fact sheet:**

How to improve every irrigation bay - an effective system for faster and more uniform irrigations

### **Technical note:**

How to improve every irrigation bay - an effective system for faster and more uniform irrigations

### **Online video:**

An improved border-check irrigation bay

### **Conference presentations:**

“Alternative designs for border-check irrigation bays” at the Irrigation Australia Conference and Exhibition in Melbourne in May 2016

“Improving border check irrigation precision by modifying the bay surface”, 2018 Irrigation Australia Conference and Exhibition, Sydney, 13-15 June 2018 (in prep)

## 6 Lessons learnt

Field experiments run on commercial farms are attractive because the experimental treatments can be cost-effectively evaluated at scale and under commercial conditions. The experiment site can also be used to demonstrate the new technology or innovation applied on a real farm, so results can be more directly relevant to farmers. However, experiments run on commercial farms that impinge on existing farm management practices are unlikely to succeed. With the best will, the objectives and priorities of the farmer for the experiment paddock and those of the researcher will not be the same. Non-treatment effects and confounded results will ensue.

We underestimated the difficulty of managing a project site that is five hours away by car. Fieldwork and extension/adoption activities had to be performed as a series of discrete three day expeditions with substantial travel overhead each time and limited contact between visits.

The project demonstration site has also highlighted that realising the full potential of the modified bay surface requires an irrigation supply system with the capability to deliver consistent, precise irrigations to each bay. While the modified bay surface can improve the performance of any bay that ponds excess surface water, for the modified bay to reach its potential it must be implemented as part of a well managed, efficient, modernised and automated surface irrigation system.

# 7 Appendix - additional project information

## 7.1 Project material and intellectual property

Include a summary of all material and all intellectual property created or arising during the period covered by the project.

Technical Report 1: Improved bay designs for the Macalister Irrigation District



M2-MID  
BayDesignTechRepo

Technical Report 2: A report on establishment of a demonstration of improved irrigation bays in the Macalister Irrigation District



M4\_MIDSiteEstabTe  
chnicalReport.pdf

Technical Report 3: A report on the results from the modified irrigation bay experimental site in the Macalister Irrigation District



MIDSiteResults technicalReport.pdf

## 7.2 Equipment and assets

## 7.3 Media and communications material

“Alternative designs for border-check irrigation bays” at the Irrigation Australia Conference and Exhibition in Melbourne in May 2016



IACConf2016.pdf

Presentation at Griffith workshop, March 2017



20170321-Morris-Sm  
arterIrrigGriffithPrese

**Fact sheet:**

How to improve every irrigation bay - an effective system for faster and more uniform irrigations



FactSheet\_2c.pdf

**Technical note:**

How to improve every irrigation bay - an effective system for faster and more uniform



TechNote\_2c.pdf

**Video:**

An improved border-check irrigation bay (in prep)

## 7.4 Evaluation report

Attach the final project evaluation report.

## 7.5 Budget

A statement of funds and contributions received and spent over the life of the project.

If practical, this section may be the final financial report (section E.4 of the grant agreement), containing:

- financial statements for the receipt, holding, expenditure and commitment of the grant, including a full reconciliation against the budget in the grant agreement and statements clearly showing expenditure against the grant
- a report of the receipt of other contributions (including the grantee's contributions), or if other contributions were not received as projected, an explanation of action taken in response to this shortfall
- the interest that the grantee has earned on the grant.

If not practical to satisfy requirements for the final financial report at the time of submitting the final report, please use this section to give a statement of the budget for the life of the project and submit the final financial report within 60 days of submitting the final milestone report.



# Smart Irrigation: when and how much

A report on the results from the modified  
irrigation bay experimental site  
in the Macalister Irrigation District

Agriculture Research technical report



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## Contents

EXECUTIVE SUMMARY .....	6
INTRODUCTION .....	7
BACKGROUND .....	7
THE SITE.....	7
METHODS.....	9
Bay surface treatments.....	9
Rainfall.....	9
Watertable .....	9
Irrigation assessments.....	9
Pasture production .....	10
Pugging damage .....	10
RESULTS AND DISCUSSION .....	11
Rainfall.....	11
Watertable .....	11
Irrigations.....	11
Pasture production .....	19
Pugging damage .....	20
CONCLUSION.....	21
REFERENCES .....	21



## EXECUTIVE SUMMARY

Conventional border-check irrigations on sites with low permeability soil profiles are inherently non-uniform because drainage of excess surface water from bays is very much slower than the process of applying the water. Water can be applied relatively quickly with modern supply systems, but once the supply is cut off system energy rapidly dissipates, leaving the excess surface water slowly finding its way down the length of irrigation bays in a process that can take days to complete.

This report documents results of a field experiment and demonstration site established in the Macalister Irrigation District (MID) of Victoria that aims to show higher irrigation performance through modification of irrigation bay surfaces to improve surface drainage. The report is a deliverable of the project *Smart irrigation: when and how much*, resourced by Agriculture Victoria, Dairy Australia and the Commonwealth Rural Research and Development for Profit Program.

The field experiment and demonstration site consisted of four border-check irrigation bays producing perennial ryegrass pasture grazed by dairy cows. The surfaces of two randomly selected irrigation bays were modified to reduce the duration of surface water ponding after irrigations and reduce variation of ponding duration within each bay.

Six irrigations on the four bays were measured during the 2016/17 and 2017/18 irrigation seasons. Accurate scheduling of irrigations proved to be infeasible using the non-modernised and manually operated farm irrigation system. The variability in irrigation applications reduced the value of direct comparisons between the conventional and modernised irrigation bays.

The experiment was able to demonstrate the effectiveness of the modified bay surface in draining excess surface water rapidly after irrigations. Pasture consumption varied between irrigation bays and between seasons, but exhibited no consistent difference between the conventional and modified bay surface treatments. Similarly, there was no difference in the observed pugging damage between the bay surface treatments.

The work at this site has highlighted that realising the full potential of the modified bay surface requires an irrigation supply system with the capability to deliver consistent, precise irrigations to each bay. While the modified bay surface can improve the performance of any bay that ponds excess surface water, it should be seen as one component of a modernised and automated surface irrigation system.

## INTRODUCTION

Farm water supply system modernisation and automation provide opportunities for more precise irrigation scheduling which is constrained by the inherent non-uniformity caused by slow surface drainage from conventional border-check bays.

Bay surface designs that improve surface drainage can achieve more uniform and substantially shorter water ponding durations. This facilitates more precise irrigation scheduling, improves pasture production and reduces deep drainage and evaporation losses, saving water and reducing the environmental impact of border-check irrigated dairy production.

This report is a deliverable of the project *Smart irrigation: when and how much*, resourced by the Commonwealth Rural Research and Development for Profit Program, Dairy Australia and Agriculture Victoria (Victorian Department of Economic Development, Jobs, Transport and Resources). The report documents results of a field experiment and demonstration site in the Macalister Irrigation District (MID) of Victoria that aimed to show higher irrigation performance through modification of the surface of irrigation bays.

## BACKGROUND

Border-check irrigation bay designs have historically focused on even application of water onto bays, which was a priority when normal bay inflow rates were less than 0.1 ML/d/m of bay width. Under these relatively low flow rates laser guided landforming of smooth bay surfaces dramatically improved the uniformity of water advance on bays and facilitated the development of larger and more economic border-check bays. However conventionally landformed bay surfaces are not particularly efficient at shedding excess surface water. This is problematic on sites where the final infiltration rate is very slow.

With irrigation system modernisation, irrigation bay inflow rates can commonly exceed 0.2 ML per day per metre of bay width. At these higher inflow rates surface water depth on bays is typically greater up to the time that bay inflow ceases, so minor variations in surface elevation have less effect on the spread of water. The adoption of higher inflow rates provides the opportunity to design non-uniform bay surfaces that can meet the requirement for even water application and substantially improve surface water drainage.

The demonstration site consists of four border-check irrigation bays producing perennial ryegrass pasture which is grazed by dairy cows. The surfaces of two randomly selected bays have been modified to firstly reduce the duration of surface water ponding during irrigations, and secondly reduce the variation of ponding duration within each bay. The modified bay surfaces should cause more rapid and more uniform irrigations with less crop stress and smaller water losses to deep drainage, leading to greater water productivity.

## THE SITE

The demonstration site is located on a commercial dairy farm at 38°24'05"S 146°55'05"E. It consists of four adjacent, near identical irrigation bays with established perennial ryegrass pasture (Figure 1).

The four adjacent irrigation bays comprising the demonstration site have been landformed and support an established ryegrass / clover perennial pasture. Bay landform features are provided in Table 1.

**Table 1: Basic landform features of the demonstration site bays**

Bay	Length (m)	Width (m)	Area (ha)	Average slope (m/m)	Gradient
3	214.5	52.7	1.13	0.002032	1 in 492
4	214.0	53.2	1.14	0.001617	1 in 618
5	212.5	54.2	1.15	0.001700	1 in 588
6	212.5	53.5	1.14	0.001735	1 in 576

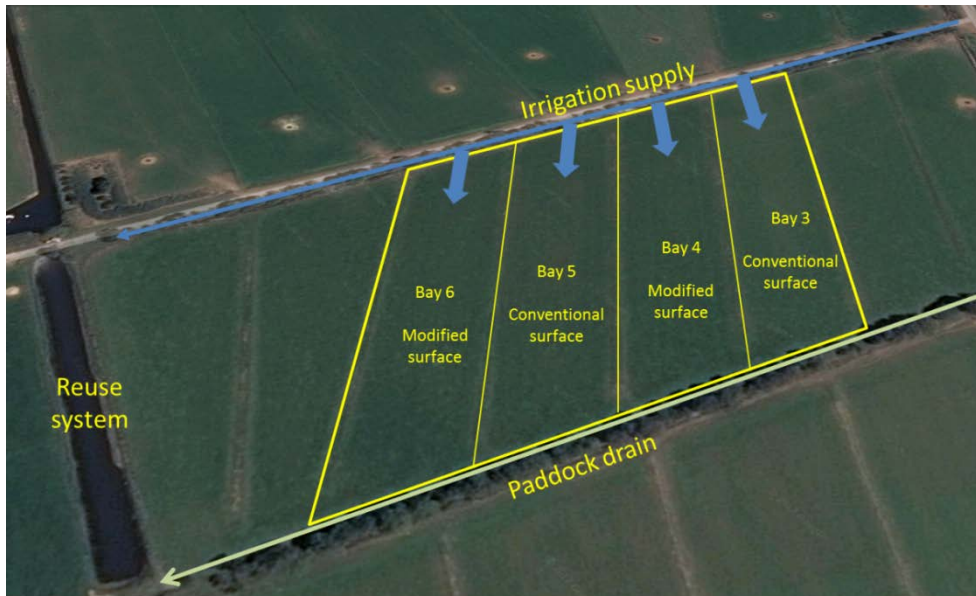


Figure 1: Site layout

The irrigation supply is from a Dethridge wheel meter via a 2km farm channel. A reuse dam adjacent to the demonstration site paddock can provide a more flexible alternate irrigation supply when required. The site drains directly to the reuse dam.

Irrigations are controlled with manually operated Padman stops (Figure 2). The bays support an established perennial ryegrass pasture with areas of prior pugging damage (Figure 3).



Figure 2: A site bay outlet



Figure 3: An example of pugging damage on the bay surface

The demonstration site lies entirely within the Wooundellah soil type, which was described by Skene and Walbran (1948).

More detail on the site and soil properties can be found in the project technical report “A report on establishment of a demonstration of improved irrigation bays in the Macalister Irrigation District” provided in April 2017.

## METHODS

### Bay surface treatments

Bays 4 and 6 were randomly selected for installation of the modified bay surface which consists of four shallow drains cut parallel with the checkbanks at approximately 8 metre spacing. The shallow drains run from approximately 10 m from the top of each bay to the paddock drain at the foot (Figure 4).

### Rainfall

An Odyssey logging tipping bucket rain gauge ([www.odysseydatarecording.com](http://www.odysseydatarecording.com)) was installed on the site to record rainfall throughout the experiment. The gauge logs each time 0.2 mm of rainfall is measured.

### Watertable

A test well was installed to 2.5 m depth (model WL1000W, Hydrological Services Pty Ltd, NSW Australia) and instrumented with a logger (Measurement Engineering Australia) to record potential shallow watertable changes throughout the experiment.



Figure 4: A shallow drain in a modified bay surface

### Irrigation assessments

#### Inflow

Farm irrigation inflow was measured and recorded with a SonTek-IQ (<https://www.sontek.com>) doppler flow meter installed in the supply channel upstream and in proximity to the bay outlets. WT-HR logging water depth meters were also placed in the supply channel to monitor water depth in the channel. A single WT-HR logging water depth meter was placed on each bay approximately 1 m from the bay outlet to record the start and end time of inflow on each bay.

#### Bay surface water

Surface water was measured on each irrigation bay during irrigations using WT-HR logging water depth meters (Intech Instruments, Christchurch New Zealand). On each bay four meters were spaced across the bay at 100 m, 150 m and 200 m from the bay outlet. Each meter logged surface water depth at 3 minute intervals throughout each irrigation, providing a water depth hydrograph at each logger location. Water depth data on the conventional bays assisted with calibration of a surface irrigation model, and on all bays was used to determine the start, end and duration of surface inundation.

During irrigations on the 28/2/2018, surface water depth was measured manually at 2 m intervals across Bay 3 and Bay 4 on transects across the bays at 50, 100, 150 and 190 m from the irrigation channel outlet.

#### Infiltration

Average bay infiltration was estimated for each irrigation on the conventional surface bays (Bays 3 and 5) by using the optimization module of the SISCO irrigation model (Gillies and Smith, 2015) to fit model output to measured irrigation data.

Final infiltration rate was measured with ring infiltrometers on Bay 3 and on Bay 4 at 50 m, 100 m and 150 m from the top of each irrigation bay. Each 34.7 cm diameter single infiltration ring was installed prior to an irrigation. Water was added as the irrigation advance reached the ring.

### Runoff

Runoff from each bay was measured by constructing a bund across the end of each bay that directed outfall to a large flume. Two WT-HR logging water depth meters were installed in the stilling well of each flume to record the flume depth hydrograph (Figure 5).

During runoff the bund and flume held back outflow which had the effect of attenuating the runoff hydrograph, however the start time of flow and the volume of flow were accurately measured, provided that the bund did not leak or overtop.

Runoff was assumed in all irrigations to have completed within 15 hours after the start of the irrigation.



Figure 5: Bay runoff flume

### Pasture production

Pasture production was measured with a 0.32 m x 0.32 m rising plate meter before and after each grazing by taking 50 pasture height measurements randomly within the top (10 m to 70 m), middle (70 m to 140 m) and bottom (140 m to 210 m) sections of each bay. Two calibration cuts each of size 0.64 m x 0.32 m were cut to ground level within each section of each bay before and after each grazing. Samples were oven dried for 48 hours at 100°C and weighed in order to convert the rising plate pasture height measurements to dry herbage mass.

### Pugging damage

Pugging damage was assessed in the pasture calibration quadrats after each grazing on a scale of 0 (no damage) to 10 (extreme damage).

## RESULTS AND DISCUSSION

### Rainfall

Figure 6 shows daily rainfall recorded at the experiment site during the project. Of note was the relatively dry winter and spring of 2017. There was only 190 mm of rainfall in the period from 1 June to 30 November, compared with the long term average at Maffra of 275 mm for this period. The dry spell was broken with approximately 90 mm of rainfall in the first week of December 2017.

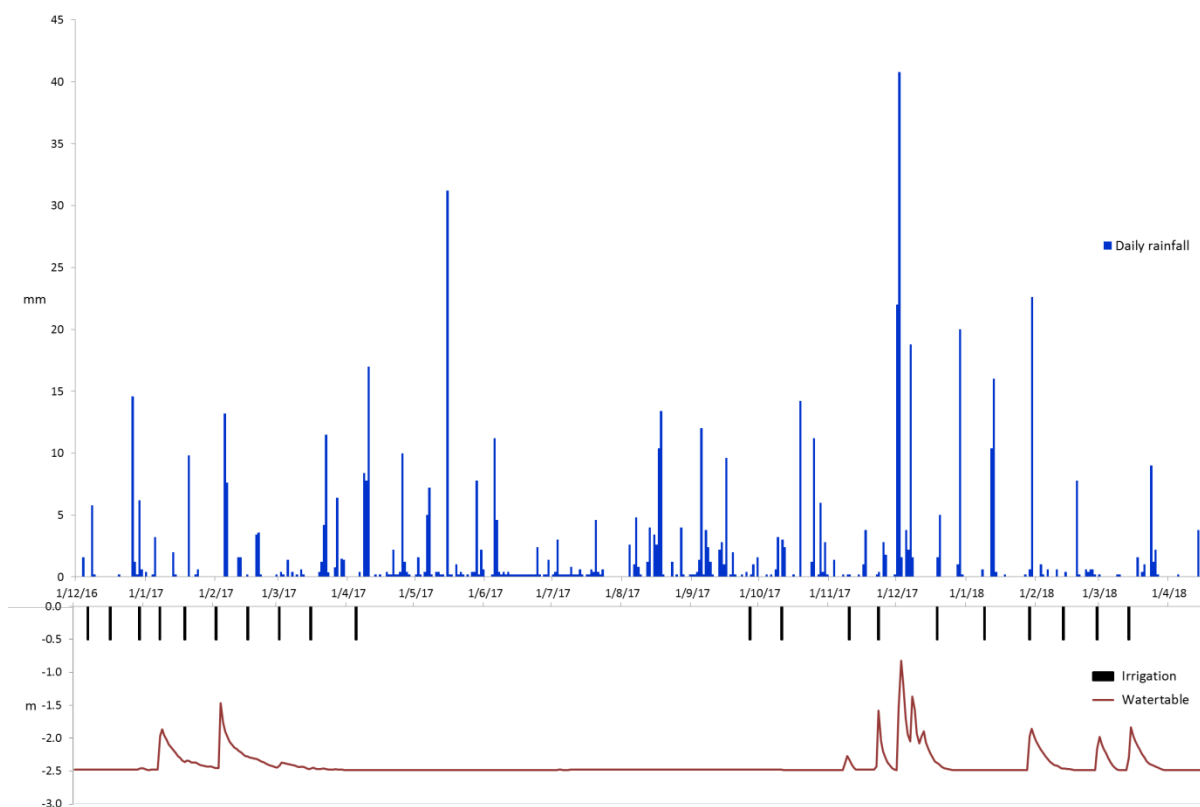


Figure 6: Daily rainfall and watertable depth during the experiment

### Watertable

Figure 6 also shows watertable data acquired at the site. The watertable rose above 2.5 m depth intermittently in response to a combination of rainfall and irrigation events. The watertable did not remain high for long, draining rapidly below our test well depth of 2.5 m on each occasion, indicating that the soil profile at the site, while dense and of low permeability, drained freely throughout the project.

### Irrigations

#### Estimated deficit

During 2016/17 daily evapotranspiration data were acquired from the nearby East Sale Bureau of Meteorology (BOM) site, 20 km to the east. In 2017/18 the East Sale site ceased providing daily evapotranspiration data, so data from both the Bairnsdale Airport BOM site, 60 km ENE, and Latrobe Valley Airport BOM site, 42 km WSW were acquired and averaged. Daily irrigation deficit was estimated by accumulating daily evapotranspiration after subtracting daily rainfall recorded at the site. Each irrigation was assumed to return the deficit to zero.

## Inflow

Inflow rates were highly variable in all irrigations, with average inflows ranging from 9.1 ML/d to 12.7 ML/d. The variable inflow rate within and between each irrigation was a consequence of the non-modernised district supply system and imprecision of manual operation of the farm supply system at this site.

As a consequence, precise scheduling of irrigations was not feasible, and the regression of estimated deficit and the applied irrigation depth is weak. Inflows were frequently substantially higher than the estimated irrigation deficit (Figure 7), leading to high runoff flows.

Inflow rate tended to increase during irrigations (Figure 8), indicating that inflow was constrained by the relatively modest size of the supply outlets. On 2/3/2017, for example, inflow to Bay 6 was initially 7 ML/d and rose steadily to nearly 12 ML/d three hours later. On 5/4/2017 the initial recorded flow of approximately 9 ML/d increased to 11 ML/d over a 6 hour period. On 28/2/2018 an initial recorded flow of 10 ML/d increased over 6 hours to more than 14 ML/d.

Due to a likely faulty meter, inflow was not recorded by the flow meter for irrigation of Bays 6 and 5 on 27/9/2017 and for irrigation of Bay 5 on 11/10/2017. The meter was replaced after the 11/10/2017 irrigation.

In addition, some recorded inflow data are probably inaccurate. For example, over a 2.5 hour period on 16/3/17 recorded inflow rose from about 9.5 ML/d to 13 ML/d before falling to 10 ML/d, with no corresponding variation in independently recorded supply channel water depth data. A similar event occurred on 11/10/2017.

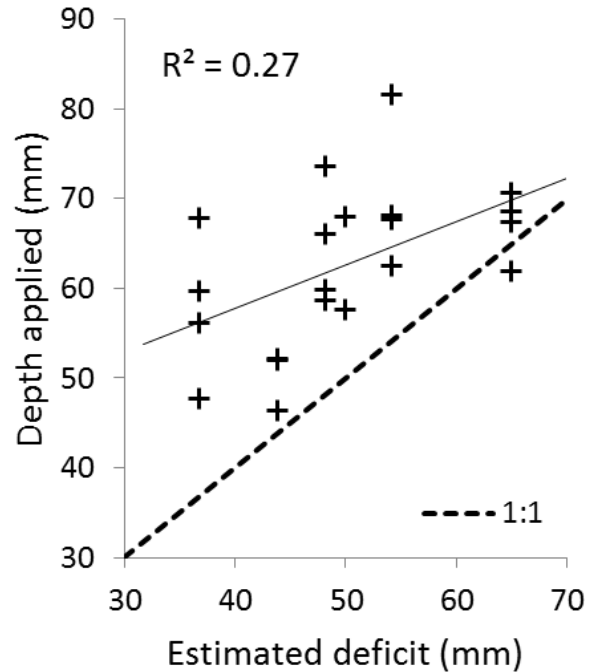


Figure 7: Regression of estimated deficit and the applied irrigation depth

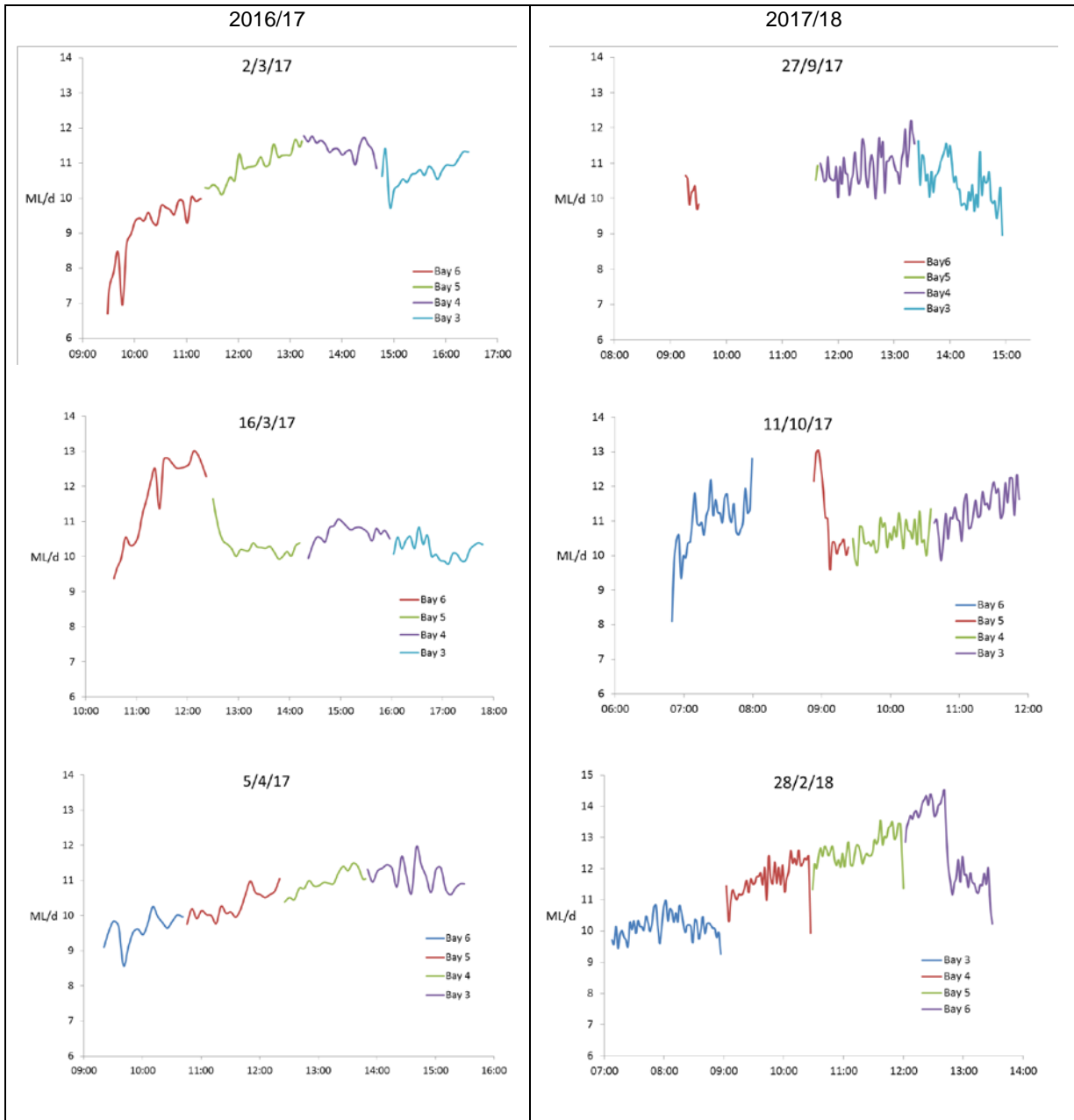


Figure 8: Doppler flow meter irrigation inflow hydrographs

## Within bay surface water

### Manually measured water depth data

Tables 2 and 3 show surface water depths measured manually at 2 m intervals on transects across Bay 3 and Bay 4 on 28/2/2018. The transects were at distances of 50, 100, 150 and 190 m from the supply channel outlet. The results from the two bays cannot be directly compared because the durations of surface inundation differ between the bays, however Figure 9 does highlight the relatively rapid drainage of the modified bay.

### Logged water depth data

Figure 9 shows the average time of irrigation advance recorded by WT-HR logging water depth meters on the conventional and modified border-check bays over six irrigations. The data indicate that the modified bays wet up more quickly than the conventional bays, and that the irrigation advance was less affected by irrigation shut-off on the modified bays.

The average measured durations of surface water ponding on the conventional and modified bays are shown in Figure 10. The modified bays consistently experienced reduced ponding duration compared to conventional bays, particularly at the bottoms of bays. Variability in ponding duration was very high, due in part to the imprecise scheduling of irrigations and to bay surface irregularities created prior to the experiment by stock and vehicle traffic.

Table 2: Measured depth of surface water on conventional Bay 3

Distance from the channel outlet (m)	Duration of inundation (hrs)	Average depth (mm)	Distance across the bay (m)																									
			2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
First depth measurements (mm)																												
50	5.1	2.2			15	1	4	5			5	2		5			1	1		3	2	8		3	1	1		
100	4.4	10.3	10	11	21	1	9	20	1	18			5	11	15	5	11	25		6	15	14	20	8	20	5	15	1
150	3.5	20.7	10	11	41	35	21	25	1	5	20	30	20	20	4	29	20	30	21	37	17	20	20	26	26	25	20	4
190	2.4	29.0	30	40	40	34	42	60	43	22	24	40	30	40	24	30	30	10	21	28	37	27	21	18	40	22		
Second depth measurements (mm)																												
50	8.1	0.7			5																					12		
100	7.4	1.8			12			5		1				1				6			1	2	10		1	3	5	
150	6.4	8.0			19	10	5	7			10	12	5	27		12	5	15	10	15	2	10	4	14	11	15	1	
190	5.4	13.8	9	25	15	11	30	25	18	6	2	20	10	22	5	18	20		12	15	4	15	11	15	30	20	1	
Third depth measurements (mm)																												
50	25.3	0.0																										
100	24.8	0.0																										
150	24.2	0.0																										
190	23.2	0.1					1	1											1									

Table 3: Measured depth of surface water on modified Bay 4

Distance from the channel outlet (m)	Duration of inundation (hrs)	Average depth (mm)	Distance across the bay (m)																									
			2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
First depth measurements (mm)																												
50	5.5	0.7		1	1			1											1			14	1					
100	5.0	0.4		1	2			6													1	1						
150	4.5	2.2		4	9	12		15						2						6		5	1	2				
190	3.7	2.2	2	5	10		1		10	10			1									15	1	1				
Second depth measurements (mm)																												
50	8.4	0.0																										
100	7.8	0.2						5																				
150	7.1	0.0				1																						
190	6.3	0.2																				5						
Third depth measurements (mm)																												
50	23.7	0.0																										
100	23.4	0.0																										
150	23.1	0.0																										
190	22.4	0.0																										

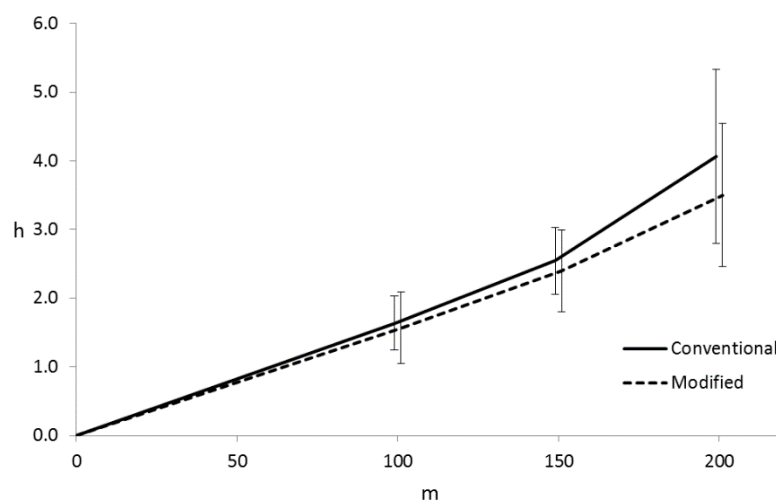


Figure 9: Irrigation advance measured for six irrigations on two conventional and two modified bays. Error bars are one standard deviation

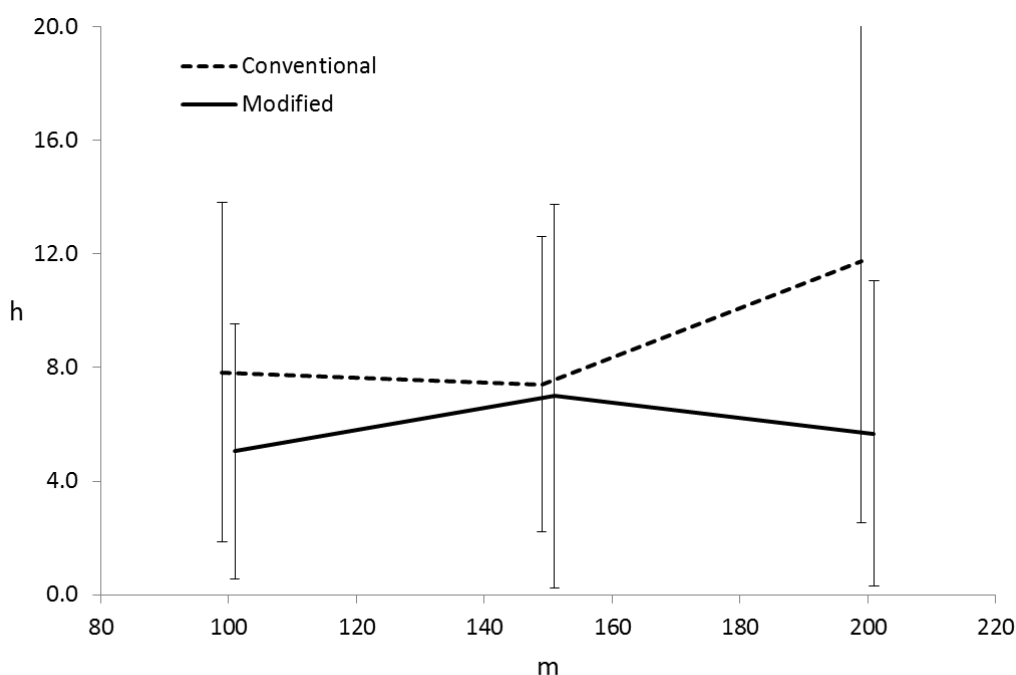


Figure 10: Average surface water ponding duration for six irrigations on two conventional and two modified bays. Error bars are one standard deviation

### Runoff

The runoff hydrographs of each irrigation are provided in Figure 11. In these hydrographs the x-axis is elapsed time since the start of the irrigation. Accurate measurement of runoff was difficult to achieve at this site. There was substantial variation in runoff volume between irrigation events, some of which overtopped the bunds constructed at the ends of the bays. There were also instances of rainfall during irrigations and of the irrigation supply channel overtopping, which added large and unmeasured inflows to bays during some irrigations.

In 2016/17 substantial leakage of bunds was observed in the field on 2/3/2017 and 5/4/2017. The flat peak of hydrographs on 2/3/2017 is symptomatic of overtopping of the bunds installed across the ends of the bays. The double peak of Bay 5 and Bay 6 hydrographs on 16/3/2017 was also recorded on the water depth loggers

within these bays and coincided with shutting off the irrigation. This appears to have subsequently caused temporary overtopping of the supply channel. There was also a recurring problem with leakage of the stilling well on the Bay 3 flume during the 2016/17 irrigations which would have caused under estimation of runoff from Bay 3 for all irrigations.

Runoff measurements were more reliable in the 2017/18 irrigations, however a 3 mm rainfall event during the irrigation of 11/10/2017 affected runoff, particularly on Bay 3.

The total runoff measured from each irrigation is provided in Table 5.

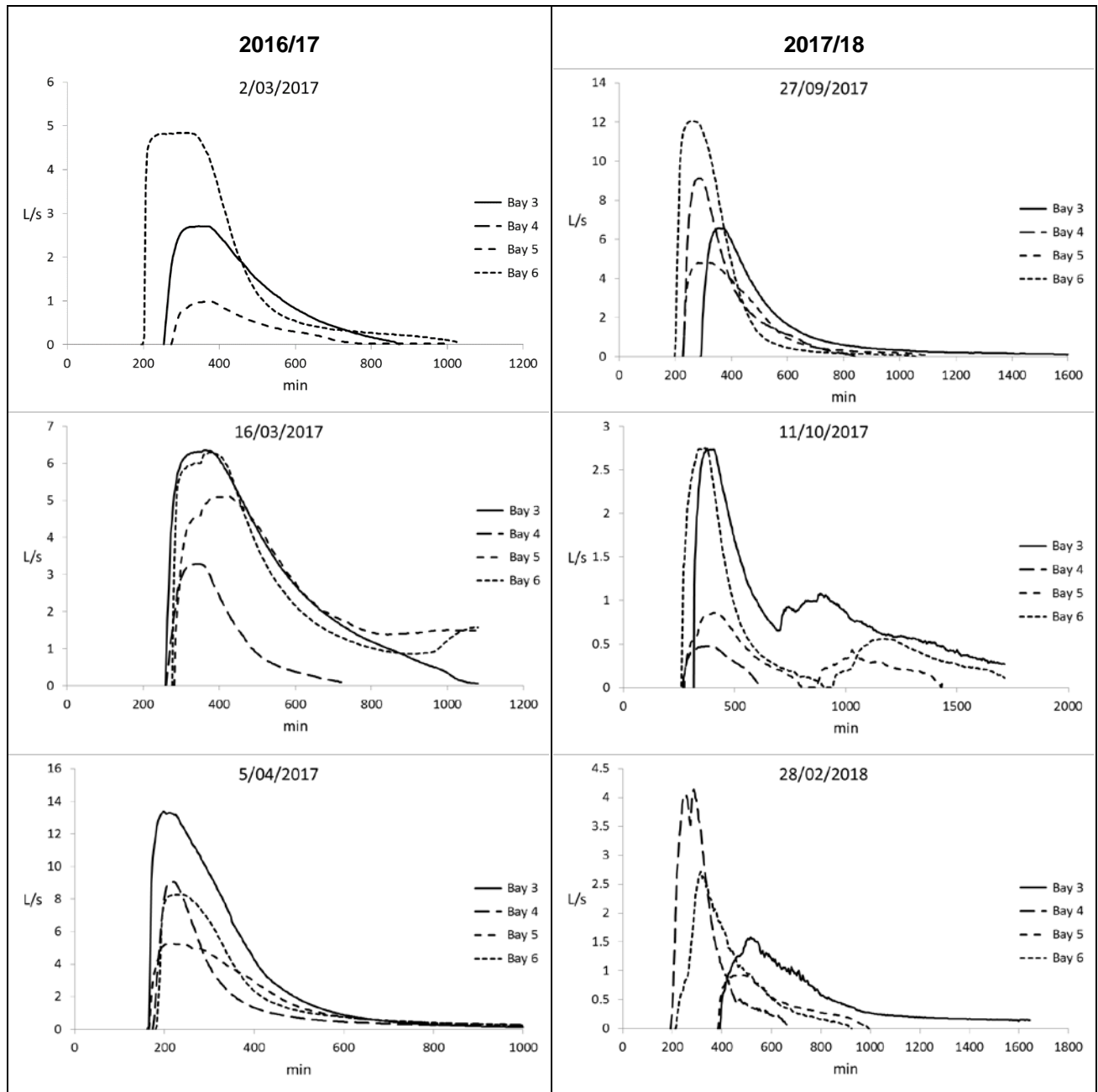


Figure 11: Irrigation runoff hydrographs

## Infiltration

Figure 12 shows results of ring infiltrometer measurements made on Bay 3 and Bay 4. The data indicate uniformity within each bay, but a clear difference between the two bays. Bay 3, with an average final infiltration rate of 1.28 mm/h could be expected to internally drain ponded surface water 0.76 mm/h faster than Bay 4.

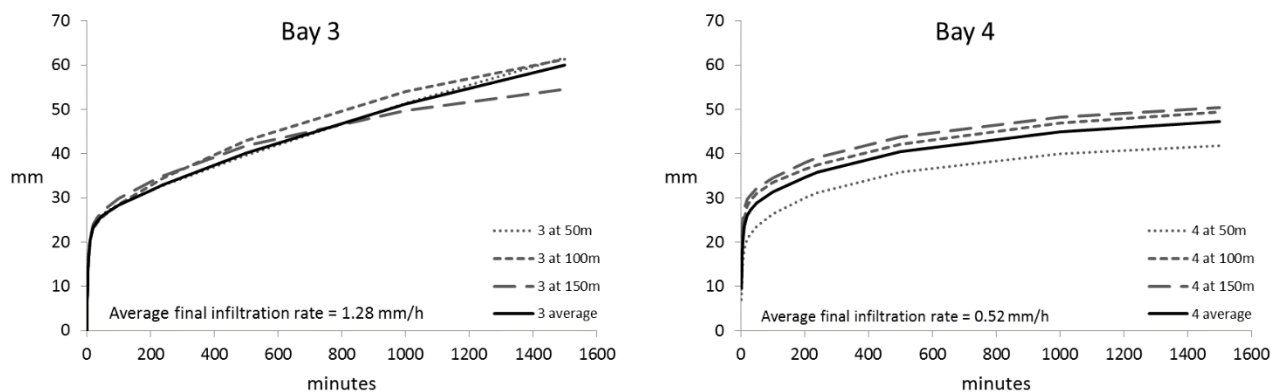


Figure 12: Soil profile infiltration on Bay 3 and Bay 4, measured with ring infiltrometers

Whole of bay infiltration was estimated on conventional irrigation Bay 3 and Bay 5 by fitting the SISCO surface irrigation model to measured advance, recession and surface water depth data for each irrigation event (Table 4).

Final infiltration rate is closely related to the hydraulic characteristics of the soil profile and in the absence of changed conditions, such as a shallow watertable of varying depth, should not vary greatly between irrigations.

The inverse modelling estimates vary from 1.23 mm/h to 0.23 mm/h between consecutive irrigations on the 16/3/2017 and 5/4/2017, reflecting substantial uncertainty in the measured data. The dominant source of uncertainty is likely to be the inflow rate.

On Bay 3 the average final infiltration rate estimated by inverse modelling was 0.72 mm/h, substantially lower than the average ring infiltrometer rate of 1.28 mm/h.

Table 4: Estimated final infiltration rate after four hours, determined by inverse modelling

Date	Final infiltration (mm/h)	
	Bay 3	Bay 5
2/03/2017	0.54	1.03
16/03/2017	1.02	1.23
5/04/2017	0.41	0.23
27/09/2017	0.68	
11/10/2017	0.84	
28/02/2018	0.80	0.50
Average	0.72	0.75

## Irrigation assessments

The experimental site has presented challenges for irrigation measurement and assessments. The site was located approximately five hours by car from the research group home base, so researchers were not able to maintain an ongoing presence at the site and instead had to undertake much of the field work as a series of three day expeditions.

The non-modernised, manually operated district and farm irrigation supply systems delivered variable inflow rates to the site and manual operation of the farm supply system was associated with variable inflow durations. This led to a poor relationship between the irrigation deficit and the quantity of irrigation water applied, which in turn caused variable and occasionally high runoff flows.

Table 5 summarises the results of irrigation measurements made on six occasions during the 2016/17 and 2017/18 irrigation seasons.

With respect to Irrigation 1 on 2/3/2017, all four runoff flume hydrographs had flat peaks, indicating that at peak flows there was flow over the bunds at the foot of each bay. It can therefore be assumed that there was substantially more runoff from each irrigation than was measured.

Table 5: Summary of measured irrigations

Irrigation	Season	Date	Estimated Deficit (ET <sub>o</sub> - R) (mm)	Bay	Bay surface treatment	A	B	C	D	E	F	G
						Inflow		Depth applied (mm)	Measured Runoff (mm)	Inferred Infiltration (mm)	Simulated	
						Rate (ML/d)	Duration (min)				Runoff (mm)	Infiltration (mm)
1	2016/17	2/03/2017	48	3	Conventional	10.8	100	66	4	62	12	54
				4	Modified	11.4	84	59	0	59		
				5	Conventional	10.9	112	74	1	72	9	65
				6	Modified	9.1	108	60	7	53		
2		16/03/2017	54	3	Conventional	10.0	111	68	7	61	19	49
				4	Modified	10.7	96	62	3	59		
				5	Conventional	10.4	108	68	10	58	6	61
				6	Modified	11.7	114	82	10	72		
3		5/04/2017	37	3	Conventional	11.1	99	68	15	53	35	33
				4	Modified	11.0	84	56	7	49		
				5	Conventional	10.3	96	60	8	52	33	26
				6	Modified	9.6	81	48	9	39		
4	2017/18	27/09/2017	50	3	Conventional	10.4	90	58	8	50	7	51
				4	Modified	10.9	102	68	9	59		
				5	Conventional		99		7			
				6	Modified		99		12			
5		11/10/2017	44	3	Conventional	11.3	75	52	4	48	0	52
				4	Modified	10.6	72	46	1	46		
				5	Conventional		72		1			
				6	Modified	10.9	78	52	3	49		
6	28/02/2018	65	3	Conventional	10.1	114	71	3	68	0	70	
			4	Modified	11.7	87	62	4	58			
			5	Conventional	12.6	90	69	1	67	2	66	
			6	Modified	12.7	87	67	3	64			

$$C = A * B * 10^6 / (\text{bay length [m]} * \text{bay width [m]} * 24 [\text{h}] * 60 [\text{min}])$$

$$E = C - D$$

$$G = C - F$$

In Irrigation 2 on 16/3/2017 the high inflow recorded by the doppler flow meter for Bay 6 (Figure 8) was not accompanied by a corresponding increase in water depth in the supply channel, suggesting error in the flow meter. The runoff flume hydrograph from Bay 6 was confounded by an unexpected second wave of inflow onto the bay about 16 hours after the start of the irrigation, presumably caused by the supply channel overtopping and flooding onto Bay 6. Runoff had not finished when flume logging ceased.

The estimated deficit of Irrigation 3 on 5/4/2017 was substantially lower than other irrigations, and would have been associated with substantial runoff from Bays 3, 4 and 5, given the depth of irrigation applied to these bays. Data prior to the start of runoff indicate that there was leakage from the stilling wells of the Bay 3 and Bay 5 flumes, and the shape of the Bay 5 hydrograph suggests that overtopping of the bund also occurred. The simulations fitted to this irrigation provide supporting evidence that there was a substantial under estimation of the runoff volume from Bays 3 and 5.

In Irrigation 4 on 27/9/2017, the doppler flow meter did not record the inflow for Bays 5 and 6.

During Irrigation 5 on 11/10/2017 there was no inflow recorded for Bay 5 by the supply channel Doppler flow meter. The Bay 3 runoff hydrograph was affected by a 3 mm rainfall event while the bays were draining.

Irrigation 6 on 28/2/2018 appeared to have no substantial data capture issues.

### Pasture production

Pasture consumption data are summarised in Table 6 and in Figure 13. The average pasture consumption rate was substantially higher in 2016/17 at 20.0 kg DM/ha/day, compared with 12.0 kg DM/ha/day in 2017/18. No difference in production was apparent between the conventional and modified bays. This is not surprising, given our inability to achieve precise irrigation scheduling at this site.

Table 6: Average rate of pasture consumption during irrigation seasons 2016/17 and 2017/18

	Pasture consumption rate (kg DM/ha/day)				
	Bay 3	Bay 4	Bay 5	Bay 6	Average
2016/17	19.6	18.6	21.4	20.4	20.0
2017/18	11.1	10.5	12.2	14.2	12.0
Average	15.35	14.55	16.8	17.3	16.0

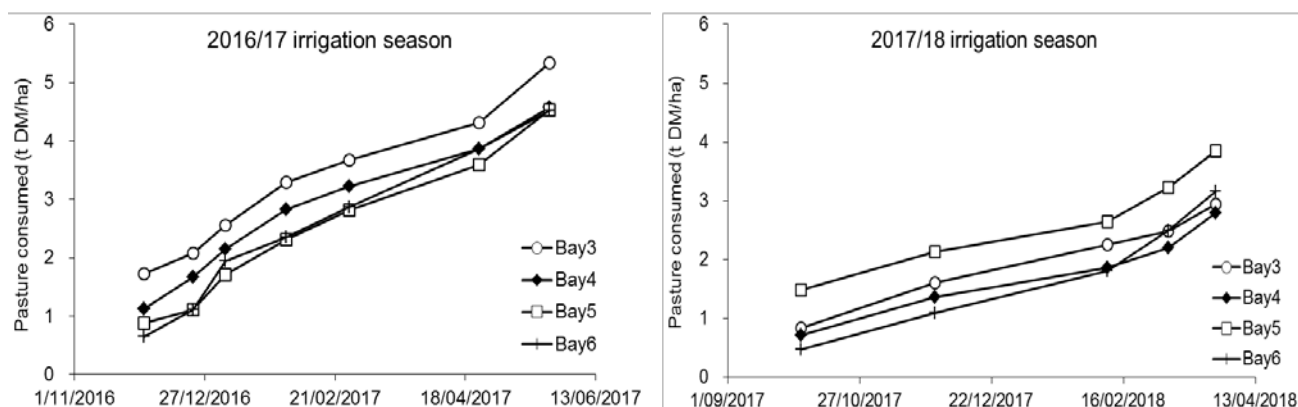


Figure 13: Pasture consumed during the 2016/17 and 2017/18 irrigation seasons

### Pugging damage

Pugging damage assessments are shown in Figure 14. There was no observed difference in incidence of pugging between the bays or between bay sectors. The data show evidence of a steady reduction in visible damage during 2016/17, and of a new pugging event in the period between November 2017 and February 2018.

Bay	Sector	2016/17							2017/18				
		1/12/16	22/12/16	5/1/17	31/1/17	27/2/17	24/4/17	24/5/17	2/10/17	28/11/17	9/2/18	7/3/18	27/3/18
3	10-70m	3.5	2.5	3.0	2.5	2.0	3.5	2.5	2.0	1.0	4.0	4.0	3.5
	70-140m	3.5	3.5	4.5	3.5	1.5	1.5	2.5	1.5	2.0	3.0	3.0	3.5
	140-210m	2.0	4.5	2.5	2.5	1.5	2.5	2.5	2.0	1.5	3.0	3.0	2.0
4	10-70m	5.0	4.0	1.5	2.5	1.5	1.5	1.0	2.0	5.0	3.5	3.5	5.0
	70-140m	2.5	4.0	1.5	3.5	1.5	2.5	1.5	1.5	2.5	4.0	4.0	2.5
	140-210m	3.0	4.0	2.5	2.0	0.5	1.0	1.5	1.5	3.0	5.5	5.5	3.0
5	10-70m	3.5	4.0	3.5	2.5	1.5	1.5	1.5	1.0		5.0	5.0	3.5
	70-140m	4.0	4.5	2.5	2.5	2.0	2.5	1.5	1.0		2.5	2.5	4.0
	140-210m	5.5	4.0	4.0	3.0	1.0	2.5	2.5	1.0		3.0	3.0	5.5
6	10-70m	4.0	3.5	4.0	3.0	1.5	1.5	1.5	1.5		3.5	3.5	4.0
	70-140m	3.0	3.5	3.5	1.5	0.5	1.0	1.5	3.0		3.5	3.5	3.0
	140-210m	3.0	4.0	3.5	3.0	2.0	2.0	1.0	2.5		2.0	2.0	3.0

Figure14: Pugging damage assessment scores after grazing



Figure 15: Typical pugging damage on the site

## CONCLUSION

A detailed comparison of the efficiencies of the conventional and modified irrigation bay surfaces has not been feasible at this site given the vagaries of the non-modernised and manually operated irrigation supply system and the substantial uncertainties this caused in our hydrological data.

Tables 2 and 3 do demonstrate the effectiveness of the modified bay surface in draining excess surface water rapidly after an irrigation, and Figure 10 shows that over the six measured irrigations the modified bays shed excess surface water more quickly than conventional bays, particularly in the bottom half of the bays.

Pasture consumption varied between irrigation bays and between seasons, but exhibited no consistent difference between the bay surface treatments. Similarly, there was no difference in pugging damage between the bay surface treatments.

The work at this site has highlighted that realising the full potential of the modified bay surface requires an irrigation supply system with the capability to deliver consistent, precise irrigations to each bay. While the modified bay surface can improve the performance of any bay that ponds excess surface water, it should be implemented as part of a modernised and automated surface irrigation system.

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# How to improve every irrigation bay

An effective system for faster and more uniform irrigations

AGRICULTURE VICTORIA

Fact Sheet, May 2018

## WHAT'S THE PROBLEM WITH CONVENTIONAL IRRIGATION BAYS?

Border-check irrigations have a fundamental problem that arises because drainage of excess surface water from bays is very much slower than the process of applying the water. Excess surface water at the top of bays must find its way to the drain at the foot of the bay by flowing across the entire downslope surface in a process that can take days to complete and produces non-uniform irrigations.

Longer periods of ponding also increase the duration of saturation in the rootzone with each irrigation. This can reduce root zone oxygen, stressing pasture and crop species while favoring weeds adapted to waterlogging. Longer periods of root zone saturation also increase vulnerability to damage by stock and machinery.

## WHY IS THIS IMPORTANT NOW?

With system modernisation irrigators have the opportunity to more precisely schedule irrigations to better meet plant water need. At the same time, new and improved systems for irrigation scheduling are the focus of active ongoing research, development and extension.

Optimal irrigation schedules for the top of conventional bays will favour unproductive swamp plants at the bottoms of bays. Optimising schedules for the bottom of bays will cause regular periods of water stress at the top.

Reducing the duration of surface water ponding on bays can also save water otherwise lost to deep drainage or evaporation, provided that surface drainage and reuse systems are efficient.

## SO WHAT IS THIS BAY MODIFICATION?

The bay modification consists of very shallow surface drains that run parallel with check-banks. The drains are installed only 1 to 2 cm deep and about 20 cm wide. They are spaced 10 to 15 metres apart, and extend from the paddock drain at the foot of the bay to between 10 and 20 metres from the top of the bay (Figure 1).

The drains are installed with a tractor mounted rotary digger. Care is taken to cut shallow drains – they do not need to be any deeper than about 2 cm. By installing the drains at a shallow depth, they can be cut relatively quickly, reducing the cost of installation and reducing the impact the drains can have on vehicles.

In 2016 we measured surface water after irrigating a one hectare conventional perennial pasture bay. The bay had been laser landformed in the previous year and looked in excellent condition with new pasture not yet fully established.

We then repeated the measurements after installing the bay modification (Figure 2).



Figure 1: Shallow surface drain installed on a pasture bay

With the surface drains installed, all areas of the bay received a similar irrigation and experienced shorter durations of surface water ponding. The irrigation schedule for this bay could be optimized and be optimal for the whole bay.

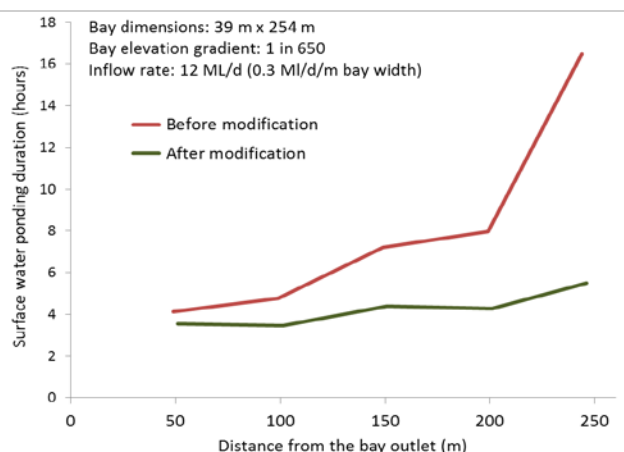


Figure 2: Measured average duration of surface water ponding after border-check irrigation on a bay before and after bay surface modification

## HOW DID YOU ARRIVE AT THIS BAY SURFACE MODIFICATION?

The modification has been used on a small number of dairy farms in northern Victoria for more than a decade, and farmers who have implemented the design are convinced of its value.

In 2015 we adapted the ANUGA inundation model to use as a two dimensional surface irrigation model. We used the model to compare a large variety of potential bay surface modifications under a wide range of bay dimensions, slopes, inflow rates, soil types and crops. The simple modification described here was the stand-out of all the bay modifications we tested, achieving rapid surface drainage and much greater irrigation uniformity on a wide range of simulated bay slopes, dimensions, inflow rates, surface roughness and soil types. While most of our field assessments have been on perennial pasture, the modification would have application on other shallow rooted crops.

Farmers with practical experience and using trial and error, and researchers taking a theoretical, computer modelling approach have independently arrived at the same modification to improve the performance of irrigation bays.

## WHAT IS REQUIRED?

### Surface drainage and reuse

An efficient drainage and reuse system is essential with these bays. When compared to a conventional bay, the modified bay surface will increase surface runoff from a given irrigation because

- less water is lost to deep drainage,
- less water remains ponded on the bay surface
- early in the irrigation some water completely bypasses the bay surface in the surface drains.

The peak runoff flow rate will also be higher because drainage from the bay surface will be much faster.

### Installation

The drain layout is measured and marked out before the drain is installed. The surface drains are installed with a rotary drain digger set to a depth of about 2 cm. Because the drains are shallow and require relatively little material to be removed, they are relatively quick to install and have minimal impact on machinery and stock.

The recommended 10 to 15 metre drain spacing is based on the experience of irrigators using the system.

For bays between 40 and 60 metres wide (i.e. most bays) this works out to between 3 and 5 drains per bay.

Experience indicates that if there is a borderline choice, opt for more rather than fewer drains.

## Maintenance

Drain cleaning is necessary to ensure the drains provide unimpeded water flow. On the farm where our experimental site was located in northern Victoria, the drains are cleaned with a rotary digger after every second grazing during the irrigation season. Care is taken to ensure minimal removal of material to prevent the drains becoming deeper.

On other sites, farmers have reduced maintenance costs by using herbicide to control plant growth in the surface drains, reducing the frequency of mechanical cleaning.

## WHAT ARE THE BENEFITS?

Farmers using the modified bays believe their pasture production is consistently high and more uniform in modified bays. Bays with surface drains are trafficable sooner after irrigations and after heavy rainfall, reducing damage.

We have not been able to show a statistically significant difference in pasture production between conventional and modified bays because of the high degree of uncertainty in pasture production measurements. To overcome this would require a field experiment on many replicated modified and conventional bays, with tight control over all the factors that affect production other than the bay modification.

We have been able to measure substantial improvements in bay hydrology. Deep drainage losses are reduced. Farmers report that improved drainage of bay surfaces allows grazing within 48 hours after irrigations and gets winter rainfall off bays quickly, reducing damage by cows.

With supply system modernisation and irrigation automation, these modified bays will enable more precise irrigation scheduling for the entire bay and make possible optimization of irrigations across the entire bay area.

## WHAT DOES IT COST?

A cost analysis based on the bay management practices of a farmer using modified bays indicates that his bay surface drain installation cost was approximately \$29 per hectare, with ongoing drain maintenance costs of approximately \$71 per hectare each year. Labour and fuel comprise 80% of this cost.

## FOR FURTHER HELP

A Technical Note with more information is available at: [agriculture.vic.gov.au](http://agriculture.vic.gov.au)

## ACCESSIBILITY

If you would like to receive this publication in an accessible format, please telephone Mike Morris, Agriculture Victoria on 03 5833 5283.

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# How to improve every irrigation bay

An effective system for faster and more uniform irrigations

AGRICULTURE VICTORIA

Technical Note, May 2018

*Billions of dollars have been invested to improve how water is delivered from dams to irrigation bays, but the investment will have little impact on production until we improve how water is delivered to plants.*

## WHAT'S THE PROBLEM WITH CONVENTIONAL IRRIGATION BAYS?

Border-check is a very common irrigation practice. It is relatively inexpensive to set up and to operate, which is why over 90% of irrigated dairy farms in the southern Murray-Darling Basin use border-check systems<sup>[1]</sup>. It is very commonly used on sites that have elevation gradients of less than 1 in 250 and soils that have relatively low permeability. Border-check does have a shortcoming, though, particularly on these relatively flat sites with low permeability soil profiles.

The problem arises because drainage of excess surface water from bays is very much slower than the process of applying the water. Excess surface water at the top of bays must find its way to the drain by flowing across the entire downslope surface of the bay. With modernised systems, applying irrigation water can be relatively quick, but once the supply is cut off, system energy rapidly dissipates. This leaves the excess surface water slowly finding its way down the length of bays in a process that can take days to complete.

In 2016 we measured residual surface water after irrigating a one hectare perennial pasture bay. The bay had been laser landformed in the previous year and the bay surface at the time of measurement looked in excellent condition. The new pasture was not yet fully established (Figure 1). The measured durations of surface water ponding at different distances down the bay are summarised in Figure 2. The much longer duration of inundation experienced at the bottom end of the bay is a characteristic of conventional bays due to slow drainage of the excess surface water from higher in the bay. The effect is more pronounced on longer, flatter bays with dense pasture and low permeability soils.

Longer duration of ponding provides greater opportunity for infiltration, so the problem that conventional border-check bays have is that they inherently produce non-uniform irrigations. Longer periods of ponding also increase the

duration of saturation in the rootzone each irrigation. This can reduce root zone oxygen, stressing pasture and crop species while favoring weeds adapted to waterlogging. Longer periods of root zone saturation also increase vulnerability to damage by stock and machinery.



Figure 1: The measured irrigation bay

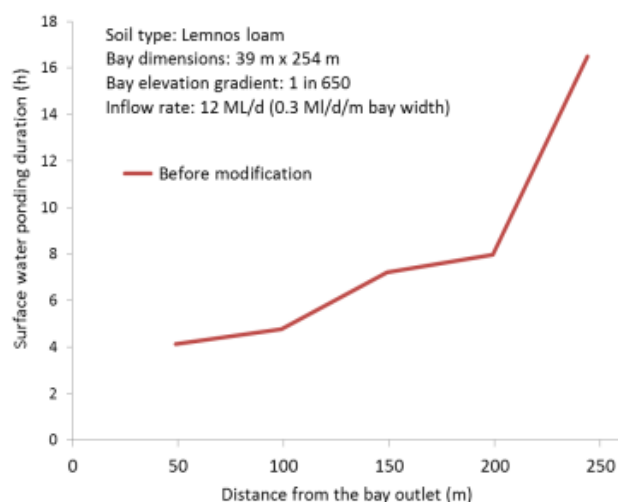


Figure 2: Measured duration of water ponding on a conventional bay after a border-check irrigation

## WHY IS THIS IMPORTANT NOW?

### Non-uniformity and irrigation scheduling

Modernised irrigation supply systems provide substantially higher, more uniform and more accurately measured irrigation flow rates that can be delivered at much shorter notice. For the first time in regulated irrigation areas,

irrigators have the opportunity to more precisely schedule irrigations to better meet plant water need.

At the same time, new and improved systems for irrigation scheduling continue to appear and are the focus of active ongoing research, development and extension.

A limiting factor for precision scheduling of border-check systems is the conventional irrigation bay itself. An optimal schedule for the top of a conventional bay will favour unproductive swamp plants at the bottom of the bay, while optimising for the bottom will cause regular periods of water stress at the top.

### Deep drainage losses

Research<sup>[2]</sup> done at Tatura prior to the millennium drought showed that there is a complex interaction between surface irrigations, root zone soil moisture and watertables less than 2 metres deep. The interaction causes deep drainage initially lost below the root zone after an irrigation to return to the root zone by capillary rise as the root zone dries, leading to much less net deep drainage.

In many areas, particularly in the southern Murray Darling Basin, watertables have not returned to the less than 2 m deep levels that were common before the millennium drought, so deep drainage losses are now likely to be much greater than before the drought, and under these conditions reducing the duration of surface water ponding on bays can save a substantial volume of applied irrigation water, provided surface drainage and reuse systems are efficient.

### SO WHAT IS THIS BAY MODIFICATION?

The bay modification consists of very shallow surface drains that run parallel with check-banks. The drains are installed only one to two centimetres deep. They are spaced 10 to 15 metres apart, and extend from the paddock drain at the foot of the bay to between 10 and 15 metres from the top of the bay (Figure 3).

The drains are installed with a tractor mounted rotary digger (Figure 4). Drains of this type have traditionally been used to improve surface drainage on poorly drained fields. In this application the drains are used to improve irrigation performance by providing faster surface drainage of the whole bay. Care is taken to cut shallow drains – they do not need to be any deeper than about 2 cm. By installing the drains at a shallow depth, they can be cut relatively quickly, reducing the cost of installation and reducing their impact on vehicles.

On bays in reasonable condition, the modification does not require any other earthworks. It can be implemented with minimal disruption to existing pasture and farm operations. In fact, on poor perennial pasture bays that require redevelopment, the current practice is to landform conventional bays and install the drains a year later, after the new pasture has established.

Advantages of the modification include its simplicity and relatively inexpensive installation which can be implemented

in stages on a farm. Disadvantages include a requirement for ongoing maintenance of the drains. This is not insignificant, given that at the required spacing there is about 1 km of drain per hectare.

With the surface drains installed, all areas of the bay received a similar irrigation and experienced shorter durations of surface water ponding. The irrigation schedule for this bay can now be optimized and will be optimal for the whole bay.

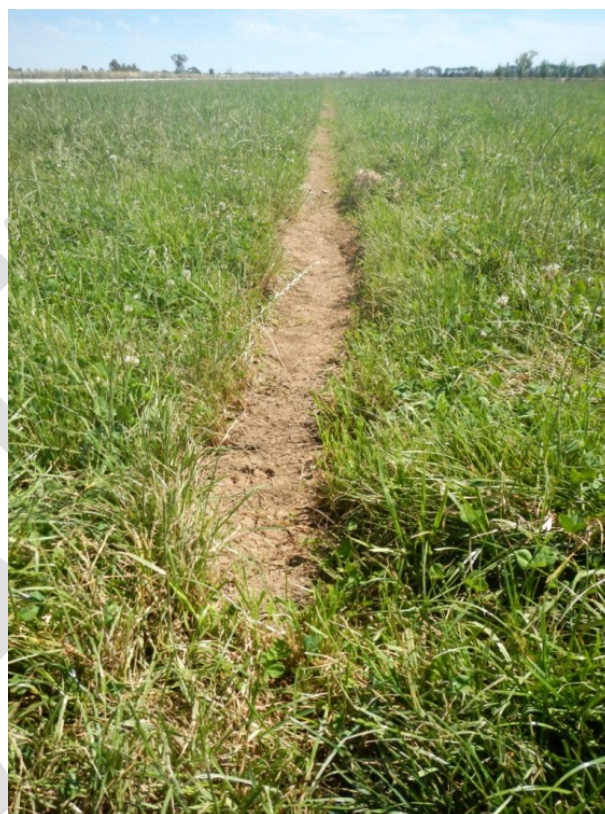


Figure 3: Shallow surface drain installed on a pasture bay



Figure 4: Surface drain installation

Figure 5 shows the effect on ponding duration that the drains had on the bay shown in Figures 1 and 2. After modification the duration of surface water ponding was much more uniform down the length of the bay and substantially less at the bottom of the bay.

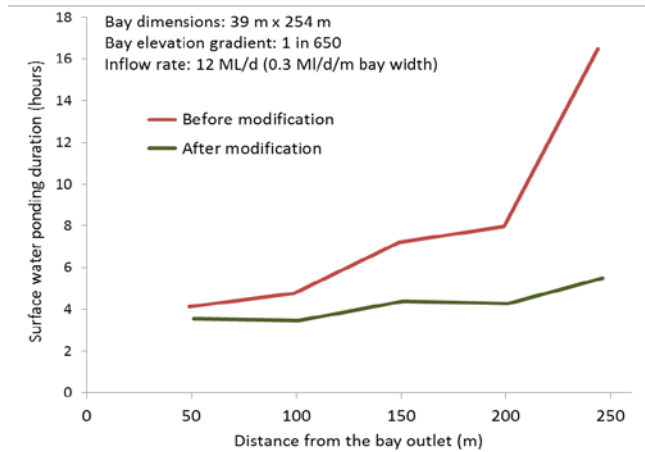


Figure 5: Measured average duration of surface water ponding after border-check irrigation on a bay before and after bay surface modification

Figure 6 shows the results of measurements made of water depth at 1 metre intervals on transects across the same bay before and after the modification. The measurements were made approximately 9 hours after initial inundation on transects at 75, 125, 175 and 225 metres from the top of the bay.

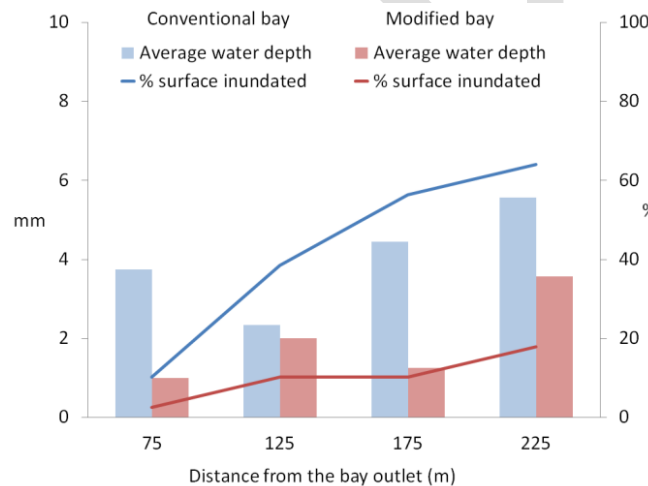


Figure 6: Surface water depth measured on transects across the bay 9 hours after inundation

Prior to modification, 60% of the bottom half of the bay remained inundated after 9 hours to an average depth of 4 to 6 mm. After modification less than 20% of the bay surface was still inundated after 9 hours, to an average depth of 1 to 4 mm.

Typical cumulative infiltration on this bay is shown in Figure 7. The bay soil profile infiltration curve has a shape that is characteristic of cracking soils like Lemnos loam<sup>[3][4]</sup>. On the basis of this curve, the modified bay was inundated for 4 to 5 hours and infiltrated between 41 and 43 mm as a result of the irrigation, while the conventional bay was inundated for between 4 and 16 hours and infiltrated between 42 and 49 mm.

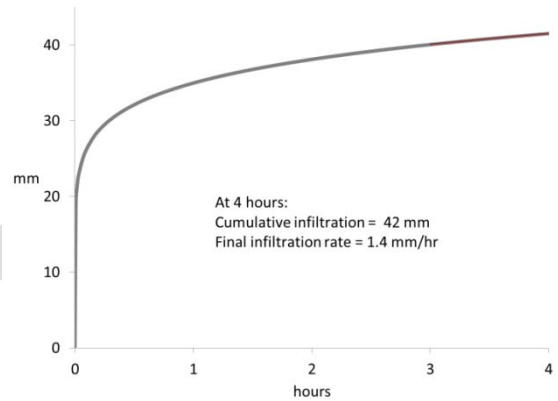


Figure 7: Typical cumulative infiltration curve on the bay that was modified

In this instance, the estimated reduction in infiltration due to the bay surface modification was about 4% of the volume of irrigation water applied.

### HOW DID YOU ARRIVE AT THIS BAY SURFACE MODIFICATION?

The modification has been used on a small number of dairy farms in northern Victoria for more than a decade, and farmers who have implemented the design are convinced of its value.

In 2015 we adapted the ANUGA inundation model to use as a two dimensional surface irrigation model. The adapted ANUGA model is able to simulate the spread, flow and drainage of water on an irregular surface, and we were able to validate its use for simulation of border-check irrigations<sup>[5][6]</sup>. This allowed us to investigate the potential for bay modifications to improve irrigation performance (Figure 8).

We used the model to compare a wide variety of potential bay surface modifications, including the shallow drains modification, under a wide range of bay dimensions, slopes, inflow rates, soil types and crops.

Farmers with practical experience and using trial and error, and researchers taking a theoretical, computer modelling approach have independently arrived at the same modification to improve the performance of irrigation bays.

The simple modification described here was the stand-out of all the bay modifications we tested, achieving rapid surface drainage and high irrigation uniformity.

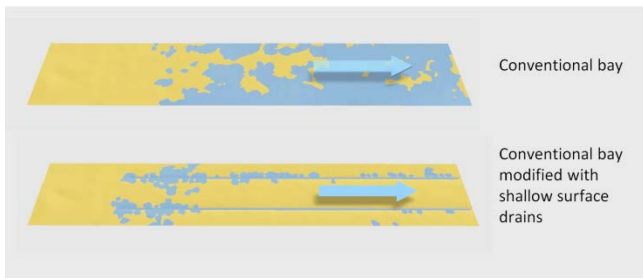


Figure 8: Model output for conventional and modified bay surfaces at 5 hours after the start of the same simulated irrigation

Importantly, our computer simulations indicated that this bay modification is very robust and will work well on a wide range of bay slopes, dimensions, inflow rates, surface roughness and soil types, reducing both the ponding duration and the variation in ponding duration within irrigation bays. It will have greatest effect on flatter bays with relatively low permeability soils.

## WHAT IS REQUIRED?

### Surface drainage and reuse

When compared to a conventional bay, the modified bay surface will increase surface runoff from a given irrigation.

For any given irrigation, the volume of runoff will be greater from a modified bay because

- less water is lost to deep drainage,
- less water remains ponded on the bay surface
- early in the irrigation some water completely bypasses the bay surface in the surface drains.

The relative contributions of these will depend on site conditions such as slope, soil infiltration and the depth of the surface drains.

Runoff volumes can to an extent be managed with accurate irrigation scheduling. Modernised irrigation supply systems provide irrigators with more timely deliveries of irrigation water at consistent and known flow rates. By irrigating modified bays at a consistent moisture deficit and with a consistent flow rate each irrigation, it is feasible to use simple cut-off timers to achieve uniform and consistently efficient irrigations.

The peak runoff flow rate will also be higher because drainage from the bay surface will be much faster.

For these reasons an efficient drainage and reuse system is essential with these bays.

## Installation

The drain layout is measured and marked out before the drain is installed. The surface drains are installed with a rotary drain digger set to a depth of about 2 centimetres. Because the drains are shallow and require relatively little material to be removed, they are relatively quick to install and have minimal impact on machinery and stock.

The recommended 10 to 15 metre drain spacing is based on the experience of irrigators using the system.

For bays between 40 and 60 metres wide (i.e. most bays) this works out to between 3 and 5 drains per bay.

Experience indicates that if there is a borderline choice, opt for more rather than fewer drains.

## Maintenance

Drain maintenance is necessary to control plant growth in the shallow drains. On the farm where our experimental site was located in northern Victoria, the drains are cleaned with a rotary digger after every second grazing during the irrigation season. Care is taken to ensure minimal removal of material to prevent the drains becoming deeper, and bays modified seven years ago are still in reasonable condition. Some erosion is occurring at the ends of the surface drains, requiring minor maintenance.

On other sites, farmers have reduced maintenance costs by using herbicide to control plant growth in the surface drains, reducing the frequency of mechanical cleaning.

## WHAT ARE THE BENEFITS?

Farmers using the modified bays believe their pasture production is more consistently high and more uniform in modified bays. Bays with surface drains are trafficable sooner after irrigations and after heavy rainfall, reducing damage.

We have attempted to measure and compare production of perennial pasture on modified and conventional bays at two sites, and measured production of forage sorghum at another. Unfortunately, pasture production data have too much noise for a statistical difference between conventional and modified bays to be determined without a large field experiment on many replicated modified and conventional bays, with tight control over all the factors that affect production other than the bay modification.

We have been able to measure substantial improvements in bay hydrology, and farmers report that improved drainage of bay surfaces allows grazing within 48 hours after irrigations and gets winter rainfall off bays quickly, reducing damage by cows.

With supply system modernisation and irrigation automation, these modified bays will enable more precise irrigation scheduling for the entire bay and make optimisation of irrigations across the entire bay area feasible.

## WHAT DOES IT COST?

The following analysis is confined to the costs incurred to create and maintain modified bay surfaces by mechanical means. Chemical weed control could reduce the frequency of mechanical cleaning required and thereby reduce the maintenance costs presented here.

With respect to fixed tractor costs, such as age related machinery depreciation, insurance, interest and shedding, were not included because the tractor was assumed to be already owned.

Variable operating costs such as depreciation due to usage, fuel consumption, maintenance and labour costs arising from installation and maintenance of the bay surface drains were included. The proportion of tractor depreciation due to usage was assumed to be 40%<sup>[7]</sup>. This figure was also assumed for usage depreciation of the implement (Table 1).

Table 1: Variable depreciation costs

	Tractor	Implement
Ownership period (years)	10	10
Value at the start of the cost period (\$)	55,000	2,700
Estimated value at end of the ownership period (\$)	25,000	800
Straight line depreciation per year (\$)	3,000	190
Depreciation due to usage (\$)	1,200	76

Hourly tractor operating costs for surface drain installation (Table 2) and maintenance (Table 3) were based on estimates from Khairo and Davies (2009)<sup>[8]</sup>. Fuel was assumed to cost \$1.40/L delivered to the farm, with a \$0.403/L tax rebate. Implement repair cost allows for annual replacement of the cutter blades and blade bolts. Labour cost for drain installation is assumed to be \$18 per hour.

Table 2: Estimated costs for surface drain installation on 100 hectares

	Tractor	Implement	Total
	\$/hr		\$/ha
Depreciation	2.11	0.76	
Fuel	14.96		
Lubrication	0.86	0.20	
Filters	0.48		
Tyres	1.96		
Batteries	0.29		
Repairs	1.64	1.50	
Labour	36.00	0.36	
Total	58.29	2.82	28.87

On a 100 hectare area, estimated total surface drain installation cost was approximately \$29 per hectare, with ongoing drain maintenance costs of approximately \$71 per

hectare each year. Labour (43%) and fuel (36%) comprise 80% of this cost.

Table 3: Estimated ongoing costs for surface drain maintenance on 100 hectares

	Tractor	Implement	Total
	\$/hr		\$/ha/year
Depreciation	2.11	0.76	
Fuel	14.96		
Lubrication	0.86	0.20	
Filters	0.48		
Tyres	1.96		
Batteries	0.29		
Repairs	1.64	1.50	
Labour	18.00	0.36	
Total	40.29	2.82	70.82

## FOR FURTHER HELP

Contact Mike Morris, Agriculture Victoria on 03 5833 5283.

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