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Modernisation of furrow irrigation in the sugar industry: final report 2014/079

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ABSTRACT

Automated furrow irrigation systems have been successfully installed and operated on 160 ha of furrow irrigation, on three farms located across the Burdekin sugarcane growing region. The once labour intensive manual irrigation management has been transformed by allowing growers to control, schedule and monitor the behaviour of the pumps, pipeline and valves remotely from a computer, tablet or smartphone.

Significant reductions of energy, water, labour and travel associated with irrigation management were seen across all three, large-scale demonstration sites. Reduced labour and travel was seen at each site, with one site registering an annual saving of at least 11,000 km travel. At two of the sites, reduced water usage of around 10% of annual usage was obtained and corresponded to a direct saving in water costs; and for one of these sites, the reduced water usage directly results in a reduced energy cost, while for the other, offers the potential to sell the saved water on the open market. Irrigation events can be scheduled to occur when they are required or to suit off peak electricity tariffs rather than when they suit labour availability.

All three farmers recognised the quality of life improvements, and notably their ability to have more time for their family and improved sleeping habits.

While assessing improvements to off-site impacts was not part of the project, they are expected as a direct result of the reduction in excess irrigation flowing through to a reduction of irrigation-induced run-off and/or deep drainage and the dissolved agri-chemicals it may contain.

EXECUTIVE SUMMARY

Irrigation is an essential part of sugarcane production in many of the sugarcane regions in Australia. Like all agricultural industries, the Australian sugarcane industry is under continuous pressure to demonstrate that it is using water resources in a profitable and responsible manner. Much of the industry is situated on the Queensland coast in close proximity to the Great Barrier Reef Lagoon, which increases the importance of good management and minimising offsite impacts. The industry has been proactive in this regard, most recently through the Smartcane BMP programme. These initiatives are a formal recognition that growers are actively engaging with the principles of sustainability and minimising adverse environmental outcomes.

Most of the irrigation in the Burdekin region is furrow irrigation, which is associated with a reputation of being inefficient and wasteful. The truth is furrow irrigation can be highly efficient on many soil types providing that it is designed and managed appropriately. Furrow irrigation involves a high labour cost, but aiming for best management practices only increases this labour requirement. The problems with rising labour costs and low labour availability in these regional areas means that growers struggle in realising the potential of their current irrigation systems.

While water use efficiency might be an important issue for the wider community, for the grower, low efficiencies equate to higher water and energy inputs. Both energy and water prices have experienced significant increases in the past few years and will continue to rise into the future. This means that any efforts to improve water use efficiency will have a direct positive impact on productivity. While some growers may be over irrigating, there are many other growers who are applying insufficient irrigation water and therefore not realising the yield potential. Technologies that improve the precision at which irrigation is applied and measure the volumes applied will assist these growers in realising that yields could be improved by applying more water in a targeted fashion.

It was proposed that conversion of traditional furrow irrigation to automated furrow irrigation would offer labour savings while allowing growers to reduce water and energy costs, improve yields and ultimately improve profitability of sugarcane production. Hence this project was initiated to scope the range of technologies and then develop and demonstrate a fully functioning furrow automation system at the whole of field scale.

The first stage of the work involved a scoping study of the available technologies across both automation systems and in-field water distribution equipment. The aim was to identify a combination of technologies which was low cost, requiring minimal changes to on-farm infrastructure while being robust and capable of providing adequate feedback and safeguards for the growers.

Following this review, automation systems were installed at three sites in the Burdekin region, specifically chosen to demonstrate the potential of automation in different soil types, water sources and set sizes. One site is gravity fed from a scheme channel, one is pumped from a river and the other farm uses a combination of creek, groundwater and recycle pumps. Across the three sites a total of 24 irrigation sets have been automated, equating to 160 hectares of sugarcane. These systems were installed and fully operational in the first quarter of 2016 and have been used to remotely control every irrigation across these 24 blocks since that time.

The system is comprised of a series of field radio nodes connected to pumps, control valves, end of row sensors, pressure sensors and flowmeters which communicate to a farm base station. Growers are now able to control, schedule and monitor all aspects of the irrigation system on these sets from a PC, tablet or smartphone connected to the internet.

All three growers are realising the benefits of automation and are planning towards expansion of the system on additional fields. The benefit realised by all growers is the reduction in labour costs, both in terms of travelling to the field and the time spent at the field managing the system. One grower was able to switch electricity tariffs reducing power costs by over 40% and save over 11,000 km per year in driving to the site. The other two growers were able to use the end of row sensors to cut back the pumping times by 1 – 2 hours per irrigation resulting in water and energy savings and the possibility of temporarily trading unused water allocation. It is important to consider that these growers were already managing irrigations reasonably well and hence the benefits should be even greater when average farmers adopt these technologies.

All components used in the automation system are commercially available through Australian suppliers. Components were selected on the basis of cost, durability, service life and practical suitability for farming conditions. The costs reflect equipment which was installed on the farms during the project. The lessons learnt during the project have identified potential improvements to the automation system such as the ability to control an increased number of irrigation sets from each field radio unit. These future improvements to system design will provide cost savings and/or additional functionality to the irrigation control systems.

This project has focussed entirely on the economic benefits which are easier to quantify. For most growers the social benefits such as improved well-being through better sleep habits and an improved family-work balance will be of greater importance than any financial gain.

The positive environmental impact generated through reduced irrigation runoff, and the associated dissolved agricultural pesticides and nutrient, have not been given an economic value. These systems serve as a tool for improved irrigation management but also provide the opportunity for farmers to record their irrigation performance and assist them to comply with Smartcane BMP.

Although this system has focussed on furrow irrigated sugarcane in the Burdekin, the concepts can be transferable to other regions and other irrigation systems such as drip and centre pivots.

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1. BACKGROUND

Furrow irrigation is widely practiced across the Australian sugar industry and is the dominant technique in regions such as the Burdekin and the Atherton Tableland. Furrow irrigation is one of the forms of surface irrigation, which is the term used to describe the range of techniques where water is applied to one of the edges of the field and is distributed across the field via gravity. Surface irrigation is often referred to as flood irrigation, implying that the water distribution is uncontrolled and therefore, inherently inefficient. It is true that a significant proportion of surface irrigation systems do perform poorly but for the most part, much of this is due to design issues or incorrect management of the system rather than an inherent problem of the system itself.

Previous studies in the Burdekin have highlighted the large range in application efficiencies across the industry and the importance of good irrigation management on that that performance. Raine and Baker (1996) monitored 6 sites over a season and observed efficiencies of 35-83%. Holden and Mallon (1997) reported values ranging from 13%-70%. Recent infield evaluations of individual events by the NCEA have found application efficiencies ranging from 35-85% in the BRIA (during 2007-2008) and 69-95% in the Atherton region (Gillies 2013). Charlesworth and Bristow (2004) measured a total of 10 irrigation sites across three seasons and found that seasonal application varied from 10 – 70 ML/ha compared to the seasonal requirement of 10-15 ML/ha. The difference between these figures is largely comprised of the deep drainage which ranged from 1-50 ML/ha. One might anticipate that the sites with higher water use should correspond with the more permeable soils, however the study concluded that the water use was not determined by the soil type or location hence indicating that water use is a function of farmer management.

The direct consequences of poor efficiency are increased deep drainage losses and tail water volumes. This loss of water becomes more significant considering the associated potential loss of both nutrients and pesticides. Deep drainage losses contribute to the rising groundwater, particularly in the Burdekin Haughton Water Supply Scheme (BHWSS), which has been identified as a potential threat to sustainable sugarcane production. Runoff arising from irrigations can be recaptured using tail water recycling systems but in many instances this water will find its way into natural streams and rivers. This is a continuous issue for the sugarcane industry with its close proximity to the Great Barrier Reef lagoon.

Simulation models serve as a tool to identify and evaluate improved irrigation practices for a given field. A good case study can be observed with the Australian cotton industry, where in the late 1990's, application efficiencies for individual irrigations varied from 17 to 100% (Dalton et al., 2001, Smith et al., 2005), with deep drainage below the root-zone identified as a major loss. Through computer modelling and optimisation with SIRMOD, Smith et al. (2005) demonstrated that increasing the furrow inflow rates above normal practice to 6 L/s, and reducing the time to cut-off (*Tco*) accordingly would increase the potential average application efficiency, *Ea,* to 75%. Later measurements collected in that industry over the subsequent years and analysed with the SISCO model indicated that growers have adopted those practices and were achieving that increased level of efficiency (Roth et al., 2014; Gillies, 2012). This example demonstrates the great potential for improvements in water use efficiency through the measurement and modelling process.

In a similar manner, modelling conducted during the previously mentioned studies in the sugar industry have suggested that efficiencies of most sites can be improved through greater control over the duration and altered flow rates. The farmers may know exactly how to achieve high efficiency but usually this involves a higher degree of monitoring and control than existing management levels. As labour costs increase, this high level of control is no longer financially or practically possible. Automation of simple, mundane tasks such as opening and closing valves or gates means that irrigation control decisions are implemented at the correct time or at least at the time desired by the irrigation manager. Automation systems also provide a platform for system monitoring which in some cases may be of greater value to the irrigator than the control aspects themselves. The ability to remotely observe system flowrates and pressures, channel levels or soil moisture status all ultimately result in the potential for improved irrigation management. Automation does not guarantee optimum performance but does provide a practical way for farmers to achieve good performance while keeping labour costs to a minimum.

An issue facing many regional communities is the availability and affordability of labour. Even those who can manage with existing labour will find any suggested recommendations to improve irrigation performance difficult to implement. Irrigation in the Burdekin is a year-long activity typically with around 20 events per block. The majority of growers are the sole worker on their property so the continuous labour requirement is far more than merely a financial strain and has impacts on their family life.

Water prices are increasing for some growers, but the more pressing issue is that of rising pumping energy costs. Investigations completed in the sugar industry have shown that irrigation is responsible for a substantial part of the whole farm energy use (Baillie and Chen, 2012). There are three options to address high pumping energy costs; (1) improve the efficiency of the pump, (2) reduce the volume of water pumped through improved irrigation management or (3) take advantage of off peak electricity tariffs. There has been a large focus in recent years on improving pump efficiency but in many cases a more significant gain can be achieved through the reduction in pumped volume arising from improving in-field efficiency. Automation offers the opportunity to achieve both reductions in pumped volumes and improved ability to operate in off peak tariffs.

Recently there has been a surge of interest in precision irrigation, which often involves some form of automation. Commercial application of automated surface irrigation is still in its infancy, with the best examples found in the northern Victorian border check irrigated dairy and fodder industries (Smith et al., 2016). These automated systems include radio telemetry and can be controlled over the internet. The automation tends to be fixed time based and rarely is capable of self-adjusting to suit the changing field conditions. More recently these technologies have been adopted by limited numbers of growers in the irrigated grains and cotton industries.

The Burdekin Irrigation Automation Trial (WaterWright, 2010) aimed to demonstrate the potential for irrigation automation. This work provided a valuable starting point and did demonstrate improvements, however it was restricted to a single site, involved limited evaluation of the irrigation performance and did not include a cost/benefit analysis. Since this study there have been significant advances in automation that are potentially applicable to sugar.

Automation of furrow irrigation is outside the scope of the small local irrigation companies, who are not aware of the available technologies and do not have the resources required to bring the technology to market. Automation is also a large step for growers who are unwilling to take the risk when these technologies have not been fully demonstrated in their own local environment.

The sugar industry poses some unique challenges for the sensing and control hardware and related communications. These devices must be cost effective and capable of withstanding harsh environments (such as high biomass crop, annual burning, harvesting and weather).

2. PROJECT OBJECTIVES

The aim of this project is to develop and demonstrate a system for adaptive automated furrow irrigation in the sugar industry. Once established these sites would be used to quantify the potential benefits of the system. This project aim will be achieved through the following objectives:

a) Establish industry focus group

The first task is to establish a local industry advisory group. The purpose of this group is to provide direction to the project team regarding industry requirements and local issues, preference for the demonstration sites and practical guidance throughout the length of the project.

b) Conduct scoping study

There are a wide range of equipment and technologies which might be applicable for automation of furrow irrigation. This study aims to conduct a review of available technologies and determine which of these would be suitable for field testing. In parallel, the project will outline the range of different furrow irrigation systems which are used in the Burdekin region. With guidance from the focus group this scoping study will aim towards the first draft of the design of the automation system.

c) Benchmark furrow irrigation performance

Before attempting to justify the adoption of automation, it is first necessary to gather information regarding irrigation management and performance of current systems. Field measurements and pump assessment data will be collated to give a snapshot of the management and performance of current systems. SISCO analysis will be used to investigate potential improved management strategies.

d) Development of the automation system

Informed by the scoping study, selected technologies will be integrated to develop the generic automation system design. A major difficulty posed is the unique on-farm water delivery infrastructure which may require a different solution compared to the automation systems used in other cropping industries or for other irrigation types.

e) Field Trials to test and evaluate the automation system

The developed automation system will be installed on one or more sites at a sufficient scale so that the full impact on water use, energy use and farm management can be quantified.

f) Deliver findings to industry

The project findings will be delivered to industry through a combination of field days, conference talks, information sheets and public media.

3. OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1. Outputs

The project set out to scope the range of technologies and then to apply selected technologies on commercial demonstration sites.

3.1.1. Adoption of project outputs

The best measure of success is when the farming systems developed by the project are adopted by the target industry. The difficulty for this project is that adoption requires significant investment by the grower. It was thought that field days at the demonstration sites would allow local growers to better visualise how the automation system might apply to their own enterprise. These events were generally successful in that Stephen Attard (AgriTech Solutions) received genuine enquires from growers wishing to have designs and quotes drawn up for their own farms.

The farm owners of all three demonstration sites have either contributed their own funds to expand on what could be achieved under the project budget or have immediate plans to expand the automation to other parts of their farms.

There has also been genuine interest from growers from other regions, e.g. Tablelands, Bundaberg, and Proserpine, in the concept of automated furrow irrigation. Personnel from the NCEA are currently giving advice on the applicability of automation in these circumstances.

The project has tested a range of sensors and devices but has relied heavily on WiSA radio nodes and software as it was the most appropriate technology for these sites and was commercially ready at the commencement of the trials. Much of the project technology is readily transferable to other providers apart from WiSA if they are deemed to be more appropriate at a different site. The success of this project has encouraged other potential technology providers to enter the market for on-farm automation in sugarcane. None of these have been implemented to date at a commercial scale in the Burdekin but it is likely that this will occur in the near future. The challenge will be to temper any potential negative outcomes from these alternative systems with the fact that this SRA project has demonstrated that automated furrow irrigation does function correctly and is commercially viable.

3.1.2. Adoption through commercial pathways

Automation systems, like any physical technology, requires a commercial provider who is willing and capable of supplying and supporting the technology into the future. If a project develops a unique piece of technology, then this product will likely die at the end of the project unless commercial parties are willing and able to market this product. Individuals have made the comment that it would be possible to instrument a farm at a cheaper price but these claims are based on raw component prices, not of the complete system installed in the field, commissioned and with ongoing technical support. All project documentation describing system costs has attempted to present these costs at a commercially viable rate, i.e. at a price that should be sustainable for a private retailer.

Each of the system components were sourced through a local provider or at the very least an Australian provider:

- WiSA radio nodes and base station – WiSA Global (Echuca, Vic)
- Pressure sensors and other misc. sensors – Pacific Rim Technologies (Townsville, QLD)
- Soil moisture, advance detection and drainage probes – ICT International (Armidale, NSW)

- Valves and pipeline – Greens Water Group (Ayr, QLD)
- Valve modifications and actuation levers – COAR Engineering (Ayr, QLD)
- Electrical installations – Laser Electrical (Ayr, QLD)
- Solar panels, batteries and electronic components – Solex (Townsville, QLD)
- Other Electrical components - Lawrence and Hanson Electrical (Ayr, QLD)

Use of local suppliers should assist in the ability to source components after the end of the project.

The most costly and crucial component of the automation system is the radio control and monitoring nodes. Farmers will only be confident with the technology if there is a local presence who is able to service and maintain these potentially complex systems. At project commencement, there was no local individual or organisation which would be able to fulfil this role. It was therefore important to identify and encourage local business to take on this role. AgriTech Solutions (Steve Attard and Michael Hewitt) have expressed interest in filling this local service provider role after the end of the project. The NCEA has involved AgriTech, more specifically Michael Hewitt, in all aspects of the installation and configuration of the system. Further adoption of the developed technology beyond the end of the current project relies on either AgriTech or other commercial providers being willing to provide the same level of service which has been made available to the three demonstration sites.

3.1.3. Important considerations for grower adoption

Regardless of how successful this project might be, adoption of these technologies is a significant expense for sugarcane growers and therefore wider adoption will be incremental. The benefits associated with the labour, water and energy savings will only increase with time, making investment in this technology more attractive.

The pathway to adoption and support is extremely important. Growers are not simply purchasing a new tool but an entire system which involves far more than simply a new piece of technology hardware. The costs stated throughout this project attempt to reflect this, as they are an estimate of what would be charged by a local consultant for the complete package including the design, installation, setting up of irrigation software, and ongoing training/support to effectively use the system.

Farmers will not become skilled in the first few months of installation. There will be a period where they will gain confidence in the system and probably keep close watch over how the automation is able to make the same control actions as they have been accustomed to doing manually. This period of time may be accelerated by targeted training and support. Fortunately, the system is somewhat modular in nature, the grower can instrument a small area of the farm and become familiar with the use of the technology before expanding to a larger area of the farm. The growers in this project have actually found that the monitoring performed by the automation system allows them to learn far more about the behaviour of their irrigation system than they were ever able to do in a manual manner. They are able to sit back and reflect on the previous event or events to observe how the flows, pressures and advance rates change between sets or over time.

The conservative economics analysis conducted indicates that there are opportunities for farmers to view automation as an investment where a positive rate of return will be generated, and not as an expense. It is also important to appreciate that the full economic benefits may take several years to achieve, given each farmer will need to develop confidence and understanding about their system. That said, in some situations, savings in water, electricity and labour alone may not justify the investment by the farmer so each grower needs to consider how automation may fit with their own farming enterprise.

The project has highlighted significant reductions in irrigation usage, in some cases this water would have been lost to the environment (through run-off and/or deep drainage). Given the potential benefits of reduced irrigation loss (and the associated nutrient and pesticide load), governments and NRM groups should consider financial support for the accelerated adoption of irrigation automation.

3.1.4. Suggested pathway for expansion of this project

3.1.4.1. New Demonstration Sites

The three demonstration sites within this project are all located within the Burdekin Irrigation area. The sites were chosen such that they reflect a substantial portion of the farm configurations within that area. The fourth site which was not progressed was meant to complete this picture, this site was on a permeable sandy loam with groundwater water sources. It is suggested that further work in the Burdekin should include a lower Burdekin delta grower with a lighter soil.

Furrow irrigation in the Burdekin differs from that in other sugar growing areas. Most notably, furrow irrigation in the southern districts of Bundaberg and ISIS tends to be more supplemental with rainfall accounting for a larger part of seasonal water use. Furthermore, all other districts apart from the Burdekin would be constrained by a lower water allocation. Some of the soils in the Atherton Tablelands have low permeability and therefore respond differently to furrow irrigation compared to the Burdekin. Water delivery infrastructure also differs between the Burdekin and most other districts.

Hence it is suggested that demonstration sites should be established in at least one southern site and one Tableland site. These demonstration sites will also be useful in terms of running local field days for interested growers who would otherwise be unable to visit one of the existing sites.

3.1.4.2. Improved Benchmarking and Study of Irrigation Performance

Previous studies in furrow irrigation have concentrated on single events or perhaps a small number of events on a single set on a farm. Quantification of water use at the whole season or whole field or farm scales has been too time consuming and too costly. Now, this project has demonstrated that automation systems do more than simply implement control decisions, they provide a continuous record of irrigation management and with added sensors also provide spatial rain information and soil water measurements.

Future work could focus on the use of this extensive series of irrigation data and how it might be of use to both growers and researchers.

3.1.4.3. Integration with Irrigation Scheduling Tools

There are a multitude of good irrigation scheduling tools which are potentially useful for the sugar industry, from the simplistic spreadsheet FAO56 calculators to the most complex crop models such as APSIM and WATERSENSE. One of the significant problems with these tools is that growers are not diligent in entering applied irrigation depths. Consequently, only a select few farmers use these tools and even for those growers it might only be limited to one or two sets in the whole farm.

Providing the system is connected to a flowmeter, the automation system records the volumes and hence depths applied to every block in every irrigation event. From here it should be a simple task to transfer these known applied depths to a third party scheduling tool. In a separate project to this SRA project, Assoc. Prof. Yvette Everingham (JCU) is building a piece of software which will transfer the data from the WiSA database to a Web server where it can then be accessed by the soil water balance model, IrrigWeb. Once operational this will mean that the web based crop water balance is automatically populated with gross applied depths as measured by the automation system.

Future research could be directed towards determining the actual infiltrated depths from the applied depths to improve the accuracy of the data being entered into the crop water balance.

3.1.4.4. Automation as a Stepping Stone to Smarter Irrigation

Sugarcane yields and therefore farm productivity is strongly linked to the adequacy and timing of irrigations. The ultimate purpose of irrigation is to supply water to the soil in order to meet crop requirements. The best crop production will occur when farmers can manage their irrigations to meet these requirements. Irrigation management can be a monotonous and time consuming task which in the case of furrow irrigation involves a high labour requirement.

Irrigation automation enables growers to carry out irrigation control operations remotely and/or schedule those operations ahead of time so they can consider irrigation management decisions when it best suits their busy schedule. There is no guarantee that this will lead to improved efficiency or improved yields. If the grower simply automates the current management, they will only realise a labour saving which can often be significant enough by itself to justify the investment. Achieving efficiency and/or yield improvements require the farmer to take advantage of the automation system by allowing the system to enable them to make better irrigation management decisions. All three growers in this project have already made changes to irrigation management as a result of this project, but it would be unrealistic to think that all growers would make similar improvements without some additional enabling technologies.

The Rural Research and Development for Profit Smarter Irrigation Project is currently investigating other technologies which can either inform the use of the automation system or possibly one day be integrated with the on-farm system. The aim of these technologies is to provide objective information on the climatic conditions driving water use, the soil moisture status of the soil or the level of stress in the crop. The ultimate futuristic goal of these technologies when integrated with the automation is a smart system which can sense crop water requirements in real time and then make the necessary management decisions in order to deliver water to the field and then to the plant. While this autonomous system might be desired by some growers, it is also important to note that many of the component technologies of this system may have direct application in both manually operated and automated systems.

3.2. Outcomes and Implications

This project has clearly demonstrated that existing automation technologies can be adapted to, and applied successfully, within typical furrow irrigated sugarcane fields in the Burdekin. The automation systems have been used continuously by the three growers for a period of over 18 months with minimal technical issues. The growers quickly adapted to using the automation system and are now moving to the next step of having sensors in the field to adjust the control of the irrigation in real time. All three growers are looking to expand their investment in the technology and other growers in the region have expressed genuine interest in adoption of automated furrow irrigation.

There are a wide range of potential benefits to the grower including labour savings, improved irrigation control, yield improvements, energy cost savings and water cost savings. The automation systems come at a cost and the ability to justify these costs is dependent on a range of factors which will vary between farms and growers. The cost benefit analysis presented in this report provides a good spectrum of the range of costs and magnitude of the potential benefits so that other growers might be able to consider the likely costs and benefits for their own circumstances.

The technologies tested at the sites are now commercially available and can be installed, serviced and supported by the Australian manufacturer and a local agent of that manufacturer.

4. INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1. Industry engagement during course of project

There has been a substantial effort by all team members in the promotion and communication of this important SRA project through a wide range of media channels. A list of these activities is given below:

4.1.1. Steering Committee Meetings

One of the early objectives was the establishment of a small group of Burdekin cane growers who would provide advice and direction for the project. Informal phone calls, emails and face to face meetings were held at various times but there were a small number of formal committee meetings throughout the project

- 16/12/2014 – SRA Brandon – Initial Steering Committee Meeting
- 3/08/2015 – SRA Brandon – Presenting findings of the scoping study and wanting feedback from the group on the establishment of demonstration sites. Invited Willy Lucas and Peter McDonnel to speak about their development of low cost automation systems. This session was followed up with email correspondence with growers to decide the way forward for demonstration sites.
- 18/03/2016 – DAF office Ayr – Update on the equipment which had been installed up until that point
- 17/11/2016 – DAF office Ayr – Update on project, discussion of observations from the first 6 months since installation. Discussion on the Smarter Irrigation project.
- Planned Dec 2017 – Final meeting as a wrap up of the project

4.1.2. Workshops and field days (at Demo sites)

One of the best ways to showcase the project is through field days where growers or other members of the public can see the working system and talk with the project farmers. There have been a number of events throughout the life of the project which have been promoted with help from Burdekin Productivity Services and Sugar Research Australia.

- 10/03/2016 - **Field Walk** at Aaron Linton's farm
- 6/04/2016 - National Water Use in Agriculture Research, Development and Extension Strategy Meeting and Smarter Irrigation for Profit Burdekin Tour at Russell Jordan's farm
- 17/05/2016 - **Field Walk** at Denis Pozzebon's farm
- 1/06/2016 – **NQ Dry Tropics Field Day** at Aaron Linton's farm (Figure 1)
- 9/07/2016 - **Field Walk** at Russell Jordan's farm (originally planned for 18/03/2016)
- 7/03/2017 - **Field Walk** at Denis Pozzebon's farm
- 9/03/2017 - **Field Walk** at Russell Jordan's farm
- 4/04/2017 - **Field Walk** at Aaron Linton's farm

- 22/05/2017 – **Canegrowers bus tour** visited Russell Jordan's farm as part of a bus tour organised by Burdekin Canegrowers
- 02/06/2017 – **Home Hill State High School**, where approximately 40 students visited Aaron Linton's farm
- 11/10/2017 – **Burdekin Water Forum field trip** to Aaron Linton's farm

Each grower has also on occasion hosted visits from individual growers interested in seeing the technology is action.

Figure 1 – NQ Dry Tropics field day at Aaron Linton's farm

Further events will be scheduled as part of the Smarter Irrigation Project, likely at Russell Jordan's farm. The project cannot thank the three growers enough in allowing these events to take place and being willing to speak with visitors and give their own authentic opinion on the system.

4.1.4. Industry presentations

There have been a number of industry presentations throughout the life of the project. Some examples are as follows:

- 20/05/2016 – **Burdekin SRA research Day**
- 5/12/2016 – **Southern Smarter Irrigation Tour** - Malcolm Gillies was invited speaker at the opening night of the tour.
- 8/02/2017 – Growers (Aaron Linton, Denis Pozzebon), and project team presented at the **Gwydir Valley Irrigators field day in Moree**. 25 Sugar Growers from the Burdekin travelled to the field day.
- 12/05/2017 – **SRA/BPS field day** in Ayr

4.1.5. Presentations to Groups and Individuals at the NCEA, Toowoomba

From time to time the NCEA hosts visits from groups and individuals where we have the opportunity to present project work and demonstrate the automation system in real time. Some examples are as follows:

- 20/09/2016 – **Professional development activity** for final year Engineering students from USQ
- 20/09/2016 – **NCEA Open day**
- 12/01/2017 – **NBN Co media Crew** filming promotional videos showcasing digital Agriculture
- 16/02/2017 – **Telstra Park Networking Event** – Attended by senior representatives from FKG, Schneider, Telstra and Farmscan Ag and several Toowoomba businesses.
- 17/02/2017 – **MP Luke Hartsuyker** Assistant minister to deputy Prime Minster Barnaby Joyce
- 28/02/2017 – **Trade Investment QLD and Austrade** including US representatives from Yamaha and Driscoll's
- 9/03/2017 – **Department of Science, Information Technology and Innovation (DSITI)**, including Director General, Jamie Merrick and selected advisors.
- 27/03/2017 – School students from **Toowoomba Grammar School**
- 5/04/2017 – **House of Representatives Parliamentary Inquiry into Water Use Efficiency**
- 11/05/2017 **– Brazilian Grain Growing Delegation**
- 15/08/2017 – **ASEAN council** visit
- 14/09/2017 – **Australia Awards African Irrigation Training** (Group of 22 participants from 10 African Nations)
- 19/09/2017 – **Professional development activity** for final year Engineering students from USQ
- 27/09/2017 – **NCEA Open day**

4.1.7. Other informal presentations

The project team has taken every opportunity to promote the SRA funded project in a range of different locations to a wide range of audiences. Some examples of this engagement are as follows:

- 10/08/2016 – **Street Science at QLD Ekka** – The focus of the Street Science Booth at the 2016 Ekka was "sugar", Malcolm attended this event for the day promoting the work of the project.
- 17/08/2016 – **QLD Tall Poppy Award** - Malcolm Gillies spoke about the project in his awards night speech
- 11/10/2016 – Guest speaker at **Bond University** Higher Degree by Research event
- 22/11/2016 – **Agfutures Conference**, Brisbane - NCEA trade stand at the exhibition associated with the conference
- 21/03/2017 – **Smarter Irrigation for Profit Annual Meeting** – Presentation by project team and Aaron Linton as grower representative
- 31/03/2017 – **World Science Festival** – Regional QLD event – Malcolm Gillies spoke with school students from several schools across the Darling Downs about the work in the project and the potential positive impact on the Reef.

4.1.8. Conference presentations

A list of conference presentations which have highlighted the work in this project is as follows:

- 25/08/2015 – **ISSCT Workshop**, Durban South Africa (Poster presentation and workshop session)
- 23/05/2016 - **Irrigation Australia Conference and Exhibition**, Melbourne – Joseph Foley chaired an extended session where both project researchers and one of the project farmers presented.
- 2/06/2016 – **SPAA/SRA Talking Precision Agriculture in Cane**, Home Hill
- 3/08/2016 – **18th Australian Cotton Conference** – This project was showcased in a session focusing on the Smarter Irrigation Project
- 12/09/2016 – **19th SPAA Precision Agriculture Symposium**, Toowoomba
- 22/11/2016 – **Agfutures Innovation and Investment Conference**, Brisbane – Prof Steven Raine presented several slides showcasing the project during his invited speaker session at the conference
- 2/05/2017 – **ASSCT Conference**, Cairns - Gillies, M., Attard, S., Jaramillo, A., Davis, M., Foley, J. 2017. Smart Automation of Furrow Irrigation in the Sugar Industry, Proceedings of the 39th Conference of the Australian Society of Sugar Cane Technologists held at Cairns, Queensland, Australia, 2 - 5 May 2017.
- 9/10/2017 – **Burdekin Water Forum** – Managing Irrigated Agriculture in Great Barrier Reef Catchments
- 20/11/2017 – **TropAg 2017**, Brisbane – Joseph Foley to present on the Smarter Irrigation Project
- 13/06/2018 – **Irrigation Australia Conference and Exhibition**, Sydney – Abstract submitted

4.2. Media

4.2.1. Video

SRA produced three Caneclips relating to the project, one for each of the three project participant growers. These videos are available on the SRA website as well as via YouTube. Links to these Caneclips are as follows:

Denis Pozzebon:
https://sugarresearch.com.au/caneclip/automation-furrow-irrigation-denis-pozzebon/
https://www.youtube.com/watch?v=7BA2fi1MqL4&t=181s

Aaron Linton:
https://sugarresearch.com.au/caneclip/automation-furrow-irrigation-aaron-linton/
https://www.youtube.com/watch?v=bK2zrs-fD8Y

Russell Jordan:
https://sugarresearch.com.au/caneclip/automation-furrow-irrigation-russell-jordan/
https://www.youtube.com/watch?v=3f0BQM5MavQ&t=206s

These videos have been reposted and linked on other sites such as the Australian Cane Farmers Website, http://www.acfa.com.au/automation-furrow-irrigation-russell-jordan/, Facebook and Twitter.

4.2.2. Radio

Denis Pozzebon, Malcolm Gillies and Steven Attard were interviewed by ABC Rural for the rural report and ABC Country Hour in August 2017. Links relating to this interview are:

http://www.abc.net.au/news/rural/2017-08-15/denis-pozzebon-malcolm-gillies-cane-irrigation/8808522

http://www.abc.net.au/news/rural/2017-08-15/smartphones-controlling-automated-irrigation-systems/8808880

4.2.3. Social Media

Pictures and posts have been shared multiple times through Facebook and Twitter throughout the life of the project. These posts have been shared by organisations such as SRA, USQ, NCEA and members of the cotton and dairy industries. Social media has also proven to be a useful tool in promoting access to the CaneClip videos, radio interview and industry events.

4.3. Industry communication messages

The aim of the project was to prove that automation of furrow irrigation would be practical and offer benefits to sugar growers. The three demonstration sites have each highlighted potential benefits, such as labour savings, energy savings and water savings. Automation also should result in small yield increases in many cases through improved or timelier irrigation management. The main, if not only downside to the technology, is the system cost. However, project communication has stressed the fact that these costs are site specific and in many cases can be repayed in a short timeframe when the potential labour, energy and water savings are accounted for.

The key messages from this project are:

1) **Automation of furrow irrigation is possible, practical and in in many cases cost effective.**
   In all three sites the system was successfully installed and the growers are realising genuine benefits.

2) **Many systems in the Burdekin can be automated with minimal changes to on farm infrastructure**
   The system was designed to be low cost, meaning that it uses existing pumps, pipelines, valves and irrigation fluming. Apart from the cost, this also means that growers do not need to learn how a new set of on-farm infrastructure should be managed, they can switch over to automated control overnight with no downtime.

3) **The installed automation systems allow farmers to control, schedule and monitor irrigations from offsite**
   Growers can now manage their entire irrigation system from source to furrow from their home office or remotely from a laptop, tablet or PC from anywhere in the world with an internet or mobile phone connection.

4) **Automation provides the major benefit of a reduction in farm labour**
   Growers might be hesitant to trust the system at first but very quickly they learn that they can manage the irrigation without having to visit the site continuously throughout the season. They can now design the irrigation schedule and onsite visits when it suits them and not when the system dictates they have to be at the site.

5) **Automation once used to its full potential allows better timeliness of irrigations leading to potential reductions in water and energy use**
   If they so choose, growers can now adjust their irrigation management to suit the field or the crop, potentially leading to significant savings in water and/or energy use.

6) **Automation permits irrigators to better target off-peak power tariffs**
   Where the system capacity allows, growers can schedule irrigations to occur at nights or during weekends to take advantage of off peak electricity tariffs.

7) **End of row sensors allow the system to adapt to changes in soil intake and/or flowrates and adjust the irrigation timing appropriately**
   The crop requirements, soil moisture content and soil infiltration rates change continuously between events or different sets. Simple buried advance sensors or drain level probes can be used to detect completion of the event and inform the system to automatically stop the irrigation and start the next set.

8) **The system is commercially available**
   The control hardware, sensors and software used in this research project are all available for commercial use and can be purchased from Australian suppliers. Furthermore, the design, installation, configuration and servicing of these systems can be carried out by a local consultant.

5. SCOPING STUDY

5.1. Introduction

The initial phase of the project was to scope the range of on-farm furrow irrigation systems in the Burdekin and the range of technologies which might be applicable for automation of these systems. An internal project document was produced: "*Technology Scoping Report for Automation of Furrow Irrigation in the Sugar Industry*" which outlined these available technologies. This chapter serves to summarise the important parts of that document.

Please note that all costs within this chapter are merely estimates, and in most cases, will be lower than the true retail price. These costs are merely provided to enable comparison of the various valves or technologies.

5.2. Typical Farm Layouts

In 2014 a number of farms were visited in order to scope some of the typical on-farm infrastructure for delivery of water from source to furrow. The forms of infrastructure are partly dependant on the geographical location of the farm within the district, which in term determines the water source.

The length of fields is roughly determined by the soil type with short field lengths (200 – 400 m) being common on lighter silty or sandy soils while longer field lengths between 600 – 1200 m being common on heavier clay soils. Fields are subdivided into sets containing between 40 – 90 furrows depending on the available flow and the desired furrow flow rates.

Sugarcane is harvested over 5-6 months of the year and it is common for parts of the same field to be harvested months apart. As a result, it is normal to have cane with a range of different stages of growth and therefore water requirements at any one time. Fortunately, irrigators prefer to harvest whole irrigation sets meaning that cane in each management unit is of the same age and same variety.

Sugarcane is planted at a range of row spacing, with the traditional configuration being a 1.5 m or more accurately a 5 foot spacing. In order to better fit with harvesting equipment, many growers have adopted a wider 1.8 m furrow spacing with a single or dual plant row on the hill between two furrows. Selected growers have adopted wider furrow spacings up to 2.4 m with dual plant row between furrows.

5.2.1. Water Sources

There are two main sources of irrigation water within the Burdekin region, groundwater from shallow bores, which are common in the lower delta close to the ocean, and scheme channel water pumped from the Burdekin River.

The majority of irrigators on the lower delta or on the coastal area adjacent to the Burdekin river delta are either solely dependent or have a significant reliance on shallow groundwater reserves. These irrigators commonly use electrically driven pumps (either submersible or non-submersible) to extract the water from the bores where the water level is commonly between 5–10 m below the ground surface. From here, the water may be pumped directly into an underground mains pipe or more commonly is pumped into the top of a concrete cylinder approximately 2-3 metres above ground surface (e.g. Figure 5-1). As a result, many of these pumps have a total static lift of 10 m or less.

Figure 5-1 – Example of (a) shallow bore and (b) groundwater pump pumping water into concrete cylinder

Many of the irrigators in the upper reaches of the catchment have the ability to source water from the surface scheme, which in the most part is delivered to the farm via an earthen open channel. In some areas, the channel has sufficient command over the field such that it is possible to deliver water to the field without any pumping. Nevertheless, in some of these cases the farmers use pumps to boost the flowrate above what the outlet structure will normally supply. In other areas, the supply channel is of similar or lower elevation to the field which requires use of pumps to supply water to the furrows.

A small number of irrigators on the scheme have water delivered via pressurised pipeline. These farmers can utilise this water straight from the supply without pumping, and in some cases, may be required to induce losses in the system to reduce the head to a level safe for the fluming.

Many irrigators have the opportunity to source water from both bores and the channel scheme, and commonly source water from both at the same time. The decision on the mix is governed by the water availability at the time and the cost to the farmer and in some cases by the quality of groundwater.

5.2.2. On Farm Distribution

The purpose of the concrete cylinder is to regulate the head (pressure) in the fluming or mains pipe downstream, thereby maintaining a safe pressure throughout the system regardless of the changing head as a result of pump operation or bore level changes. This concrete cylinder may be either:

1) connected to a buried mains pipe (concrete or HDPE),
2) connected directly to fluming through one or two valves which delivers water to the adjacent set of furrows only,
3) connected directly to fluming through one or more valves which delivers water to other sets, or
4) some combination of the above.

5.2.3. Infield Delivery

5.2.3.1. Fluming and Fittings

Almost all furrow irrigation in the Australian sugarcane industry is performed using low pressure flexible walled gated pipe, referred to as fluming. Common fluming sizes are 10”, 12” and 15” (254, 305 and 381 mm). The flow of water into each length of fluming is regulated using a pipe valve, which is most commonly a form of butterfly valve. Fluming is a thin walled plastic pipe which is inexpensive, light weight and consequently has a low maximum pressure limit. In reality, it is normally the cups that will fail before the fluming reaches burst pressure. Most farmers opt for the lowest cost fluming option but there are other grades and types available which may be used in adverse conditions. For example, one farmer uses a 2 m length of higher grade fluming for the section of pipe immediately downstream of the butterfly valve because of the flapping that occurs. Some initial scoping has not uncovered any practical alternative to flexible pipe.

Costs of the fluming and associated clamps is relatively low compared to the remainder of the automation system but still might be important for a new site or conversion of a site from another irrigation type. The approximate costs based on quotes obtained during the project are given in Table 5-1. Also contained in this table are the prices for the Tee fittings which are often used instead of concrete cylinders. The cost for a 100 m roll of 12” fluming, 66 cups and 1 fluming clamp is $291 or approximately $72.84 per hectare for 400m long drills.

Table 5-1 –Example costs of fluming and fittings (rough prices based on quotes)

10” Poly Tee	$90
12” Poly Tee	$110
10” x 100m poly fluming	$200
12” x 100m poly fluming	$230
400 chino fluming cups	$190
10” or 12” fluming clamp	$30

5.2.3.2. Outlets

Outlets are inserted into the fluming for every furrow, the most common outlet and lowest cost option is the chino “cup” which inserts into a cut circular hole in the fluming. These cups are available in five preformed sizes (black, red, white, blue and yellow) as shown in Table 5-2 and also as a “blank” or closed cup (Figure 5-2.a) which may be hand cut to the desired size. Although farmers may cut this blank cup to any size, the blank cups contain markings for 25, 33, 37 and 50 mm sizes.

Figure 5-2 – Fluming Outlets – (a) blank cup, (b) hand cut black cup, (c) Bartlett outlet with adjustable insert

Assuming the cups are at pipe centre line, typical heads vary from 200 mm to 500 mm above the centreline (or 307 – 628 above ground). Combining these common cup sizes with typical heads allows farmers to achieve flows up to 4 L/s per furrow. Bartlett, a producer of fluming rarely seen in the Burdekin, manufactures a stronger woven plastic fluming and a unique adjustable style outlet (Figure 5-2.c) which can be opened and closed simply by turning the inner section by 360 degrees. If the insert is removed these outlets can deliver a flow higher than the equivalent 50mm standard cup up to 5.53 L/s under 500mm of head.

Table 5-2 –Cup sizes and flow rates for fluming

Type	Size	Flow (L/s) at Head of		
	(mm)	200mm	300mm	500mm
Black	12	0.15	0.18	0.24
Red	16	0.2	0.33	0.42
White	22	0.50	0.62	0.80
Blue	30	0.94	1.15	1.48
Yellow	38	1.51	1.84	2.38
Black hand cut Max	50	2.62	3.21	4.13
Bartlet open	--	0.95	1.19	1.58
Bartlet no insert	50	3.72	4.43	5.53

The traditional cup style outlet results in a concentrated high velocity flow of water which when impacting the furrow may cause erosion, particularly for the higher cup sizes. One alternative is to use a sock (Figure 5-3) to dissipate the flow and/or discharge the flowing water down at the base of the furrow to minimise any erosion due to the impact of the falling jet of water. Depending on the tightness of fit, these outlets may result in increased flows compared to similar sized cups at the same head. The flow from an outlet is governed by the head above the outlet point, and if the sock is pressurised and flowing full this means that the outlet is lowered in respect to the pipe centreline potentially resulting in increased head and therefore increased flow for the same pipe centreline pressure.

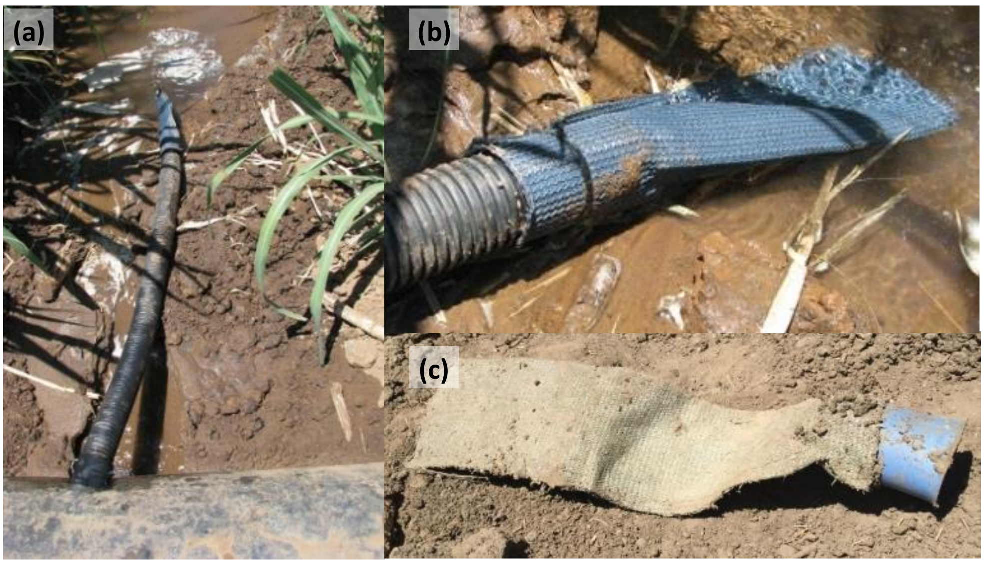


Figure 5-3 – Examples of sock outlets (a & b) corrugated drainage pipe sock (c) cup and fabric sock

5.3. Valves and Fittings

There is a large range of valves available for control of water flow at the upstream end of the fluming. This section will outline several types which may be suited for this project while ignoring those types which will not be suitable (e.g. globe valves or ball valves)

5.3.1. Butterfly valves

Butterfly valves consist of a metal disc which pivots around an axis perpendicular to the flow direction. The disc is typically connected directly to a manually operated lever (Figure 5-4.a). They are similar in action to ball valves but are more suited to larger diameters whilst ball valves are normally restricted to small pipelines. There are also UPVC and poly models of butterfly valves available.

Rotating the lever and attached plate through 90 degrees causes the valve to change from fully shut to fully open. The disc remains in the path of the flow even when the valve is fully open which will cause a slight head loss. Levers usually suffice for small diameters but a common option for larger sizes is the use of a manual wheel which is connected.

Figure 5-4 – Examples of butterfly valves (a) 300mm lever Wafer (IrrigationDirect, 2015), (b) Honeywell V4 with actuator (Honeywell, 2015), (c) Pentair Keystone F222 gear operated Butterfly (Pentair, 2015)

Almost all of the valves currently used to control water delivery to the field are butterfly valves. Most of the butterfly valves in the region are supplied by Greens Water Group, a local company based in Ayr. Some examples of valves installed in the field on poly risers are shown in Figure 5-5. The Greens butterfly valve follows the same standard design of other manufacturers but is of lower pressure rating.

Figure 5-5 – Examples of butterfly valves currently used by farmers: (a) T fitting with two geared butterfly valves, (b) T fitting with two lever action valves.

Sourcing valves from other industries generally leads to higher prices because those valves could be designed for higher pressure or fluids other than water. For example, with the 300mm gear operated valve, the locally available valve is close to $600 whereas the industrial grade valve used in the gas industry is over $1,000.

Many suppliers of valves provide engineering specifications including the torque required to operate the valves, this data does not appear to be available for the Greens valves. Butterfly valves are possibly the lowest cost standard valve which is appropriate in this situation, as shown in Table 5-3 prices vary from $300 to $750 per valve. One of the reasons for the large variance in price for these valves is the different pressure ratings between the valves quoted. All valves listed in Table 5-3 have pressure ratings far in excess of what is required for this application; although it may be possible to reduce the cost by selecting a valve with lower rating the scoping study did not uncover any possibilities.

Table 5-3 –Example butterfly valves and prices (based on quotes obtained in 2014-2015)

200mm lever operated butterfly wafer	$335
200mm gear operated Pentair Keystone butterfly	$500
250mm lever operated butterfly wafer	$294
250mm gear operated butterfly wafer	$434 - $525
300mm lever operated butterfly wafer	$420
300mm gear operated butterfly wafer	$589 – $1,012
*250mm Bray Series 30 actuated butterfly valve	$2,200
*250mm 16 Bar butterfly with 0M-5 12V Actuator	$2,550
*300mm Bray Series 30 actuated butterfly valve	$2,908
*300mm 16 Bar butterfly with 0M-4 12V Actuator	$3,245
*315mm (12”) PolyProp butterfly valve with 24V actuator	$4,600

*** includes electric activator**

The rotation of the disc inside the valve seat involves a significant amount of torque which is evident in the fact that many of the larger valves have the option for a gear reduction manual actuation rather than the lever. There are a number of different factors which contribute to the torque required to open butterfly valves. The most important factor is the seating unseating torque which represents the force required to move the disc against the valve seat. Those that provide this data give required torques for a range of different pressures, increasing as pressure increases, for example the Bray 300mm butterfly ranges from 315, 386, 437 Nm for pressures of 0, 50 and 100 psi. Torque values for a range of different butterfly valves are shown in Table 5-4.

The magnitude of these torque values requires either an actuator with a large gear reduction and therefore slow opening and closing speed or an actuator with high electrical current draw. These torques also give some context to the anecdotal comments that farmers have trouble shutting valves by hand or may bend the actuation lever. Consider a torque of 300 Nm, on the lower side of many of the valves in Table 5-4. With a lever length of 320 mm this would require a force of 937.5 N perpendicular to the lever or the equivalent of a 96 Kg person standing on the far end of the lever. Therefore, even when the farmers are stating that it is becoming too difficult to open the valves manually it is more than likely that the torque required to open the valve is still within the design limits of the valve.

Table 5-4 –Recommended actuator torque for various butterfly valves

Valve	Torque (Nm)	Type
Burkert 200mm	280	S/U with safety factor
Burkert 250mm	450	S/U with safety factor
Burkert 300mm	624	S/U with safety factor
Apollo 300mm	290	Seating/Unseating
Bray 300mm	315 (305)	S/U for general purpose (lubricated)
VFB 300mm	565	Closest available size
AAP industries 300mm	343	
250mm	400	Supplied size
300mm	500	Supplied size
Honeywell V5422 250mm	250	Supplied size
Honeywell V5422 300mm	600	Supplied size
Honeywell V4 300mm	400	Supplied size
Pentiar Keystone 300mm standard	350	S/U for zero pressure
Pentiar Keystone 300mm undercut	226	S/U for zero pressure
FIP FE PVC-U 200mm butterfly	140	Torque at max working pressure
FIP FK PVC-U 300mm butterfly	330	Torque at max working pressure

S/U = Seating/Unseating Torque

5.3.2. Knife valves and Slide Valves

Knife valves and slide valves (Figure 5-6) have a similar action to a standard gate valve except that the gate is much thinner in relation to the pipe diameter. Here a thin disc or plate, typically metal, slides along a groove in a perpendicular direction to the flow. The thin sharp edge of the plate causes these valves to be better suited for slurries and solids than gate valves, but they generally have lower pressure rating. Like a gate valve, when opened the plate is completely outside the path of the water flow.

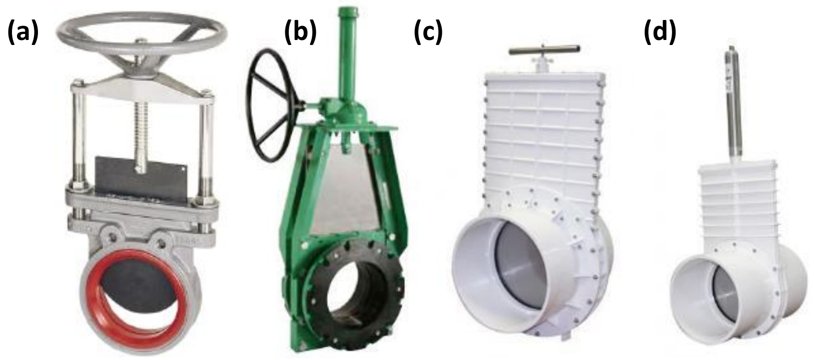


Figure 5-6 – Slide Valves (a) Pentair Keystone 951 lined Knife Valve (Pentair, 2015), (b) Pentair Clarkson KGA heavy Duty Knife valve (c) Valtera slipxslip 12" PVC slide valve (d) 8" slip-slip PVC slide valve with pneumatic cylinder (Valterra, 2015)

These valves have the advantage that they may be actuated directly with a linear actuator without the need for any additional gears or levers. Some examples of these valves are supplied with pneumatic actuators or hydraulic rams. Many of these valves are fitted with a threaded rod (e.g. Figure 5-6.a and b) for ease of actuation. Those knife valves without geared operation may be difficult to open and close manually in the event of actuator failure.

Table 5-5 –Example knife style gate valves and prices

300mm Knife Gate valve	$3,350
225mm PVC slide gate valve	$610
315mm PVC slide gate valve	$740
12” PVC slide gate valve with stainless steel paddle	$670
10” PVC Valtera slide gate valve with stainless steel paddle (Amazon)	$533
12” PVC Valtera slide gate valve with stainless steel paddle (Amazon)	$663
10” VOLT Cast Iron Knife Valve with Pneumatic Actuator	$2,465.00
12” VOLT Cast Iron Knife Valve with Pneumatic Actuator	$2,930.00

It is common to find pneumatic actuators for these valves but less common to find electric actuators, possibly due to the forces involved. Calculations based on the air supply pressures and cylinder dimensions of the Keystone valve suggest forces of 13 kN for the 300mm size and 7 kN for the 200mm size. These values are at the limit of what can be achieved with DC linear actuators as shown in section 5.4.1.

5.3.3. Surge Valves

Surge valves are T-shaped pipe fittings that are specifically designed for surge flow furrow irrigation. Surge irrigation involves applying a high flow rate in an on-off fashion until water reaches the end of the field. On some soils, the surface of the furrow consolidates during the off phase thereby reducing the soil intake rate for any subsequent cycles. During the next cycle, the water quickly advances down over the previously wetted length of the furrow and then advances along the next dry section. The final result, on suitable soils, is that the advance phase can be completed more rapidly and with less water. Surging is rarely practiced in Australia.

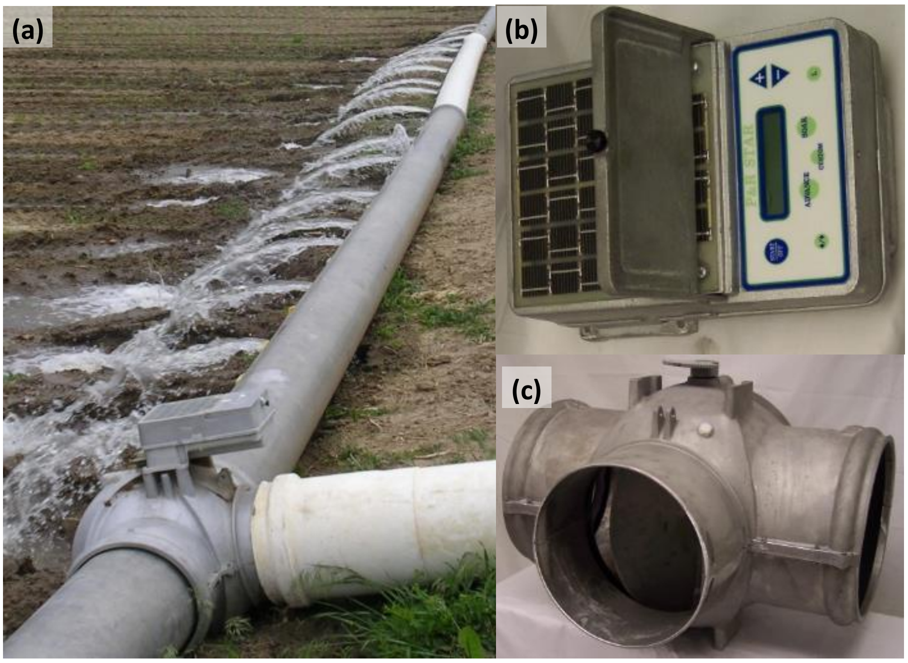


Figure 5-7 – Surge valves (a) installed in field, (b) Metal Star Controller, (c) 12” Surge valve (P&R, 2015)

P&R Surge valves (Figure 5-7) offer a simple way to achieve this intermittent water application. This T-shaped valve directs water to one side at a time and switches based on a predefined timer program.

There are three different controllers: Basic which has a single dial to specify a total advance time; JRIII which has both an advance time dial and soak time dial; and Star System which has similar functionality but with a LCD screen. These valves only have the capability to supply water to either the left or right sides and no ability to shut water off.

5.3.4. Check Valves

Check valves are used predominantly at the upstream end of a pump suction line to ensure pipe remains full of water and the pump is primed when the flow stops. Smaller check valves tend to use a ball which is held closed by a spring. Swing check valves are more common for larger diameters and are characterised by a disc which swings shut to prevent backwards flow. They may be either single disc (Figure 5-8.d) and hinged on one side or dual disc (Figure 5-8.c) and hinged in the middle. The single disc poly check valves shown in Figure 5-8.a use a spring assisted swing check (Figure 5-8.b) to improve the seal.

Most valves induce a slight head loss, even when fully open. Some check valves such as that depicted in Figure 5-8.b have a minimal loss (< 0.25m for 200 L/s) as the mechanism is essentially out of the flow path when fully open.

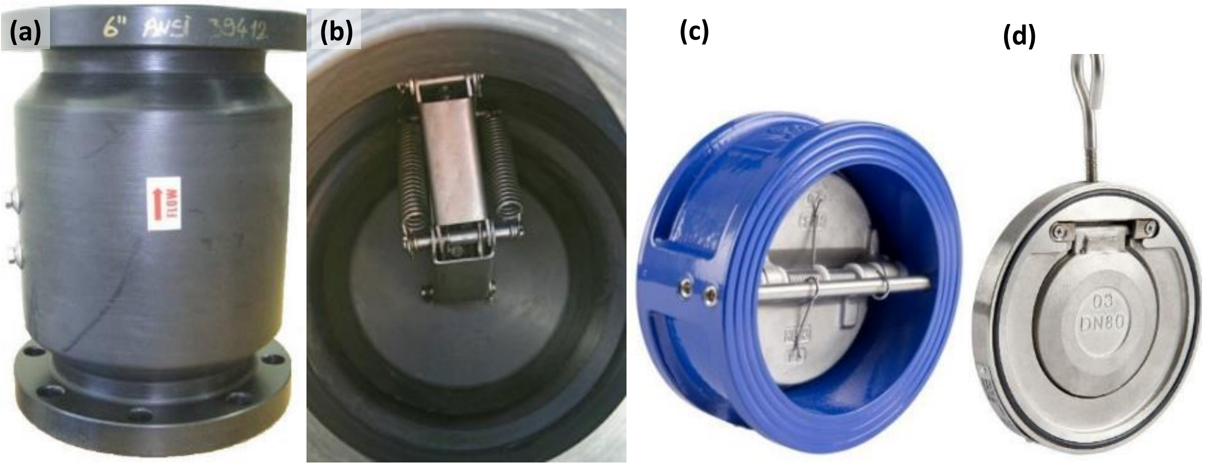


Figure 5-8 – Examples of check valves (a) Poly swing check valve (Irrigationwarehouse, 2015), (b) Poly swing check valve mechanism, (c) Duo (Dual disc) cast iron wafer check valve (ProcessSystems, 2015), (d) S/Steel wafer swing check (ProcessSystems, 2015)

Table 5-6 –Example check valves and prices

300mm S/Steel 16 bar wafer swing check	$1,700
250mm 16 Bar Duo Check wafer Cast Iron	$595
300mm 16 Bar Duo Check wafer Cast Iron	$830
12” Steel wafer check valve	$3,348
250mm Poly Check Valve	$1,449
300mm Poly Check Valve	$1,822
10” Poly check valve with s/steel mechanism	$1,771
12” Poly check valve with s/steel mechanism	$2,227

It is proposed that the dual disc check valve such as depicted in Figure 5-8.c can be modified such that the opening and closing of the discs is actuated by a cable attached to a winch as shown in Figure 5-9.

In this schematic, the water pressure upstream of valve will force the flaps to swing open and the cables will pull the flaps closed. The force required to close the valves should be minimal due to the low pressure heads in the T-piece. The main problem with this idea is the exit of the cables from inside the valve to the outside of the pressured pipeline. The design might be more adaptable to cases where the middle of the T is open to atmosphere, i.e. a concrete cylinder. This prototype was not investigated any further once it was found that the linear actuator design was simple and cost effective.

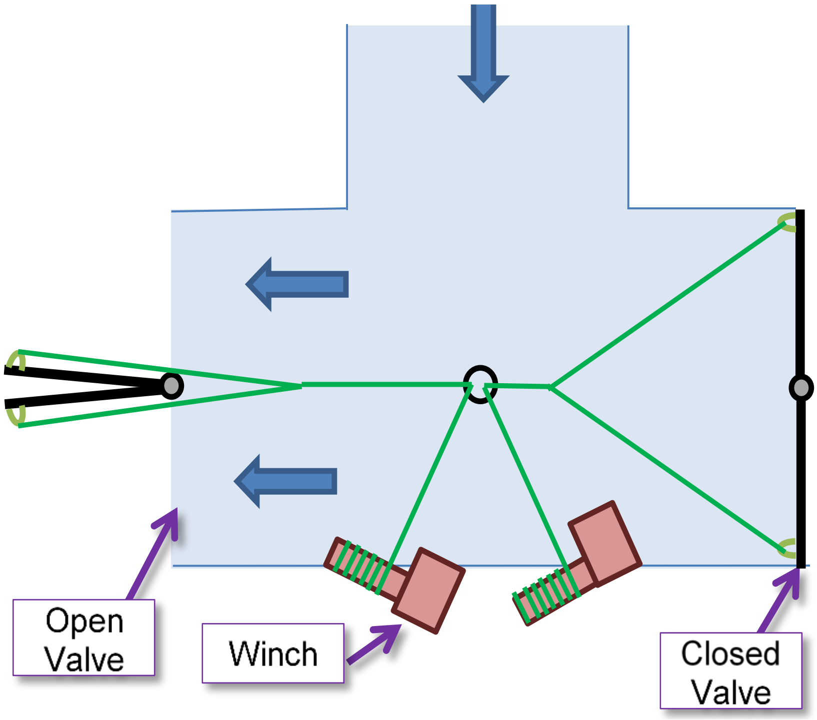


Figure 5-9 – Potential design for active check valve

5.3.5. Pinch Valves

Pinch valves consist of a flexible, typically rubber section of pipe housed within a slightly larger section of rigid pipe. The flexible pipe is squashed until it completely seals the flow. They may be actuated pneumatically by pumping air into the region between the inner rubber section and outer rigid section (e.g. Figure 5-10.e) or by using a gate (e.g. Figure 5-10.c) which pushes down on the middle of the flexible section.

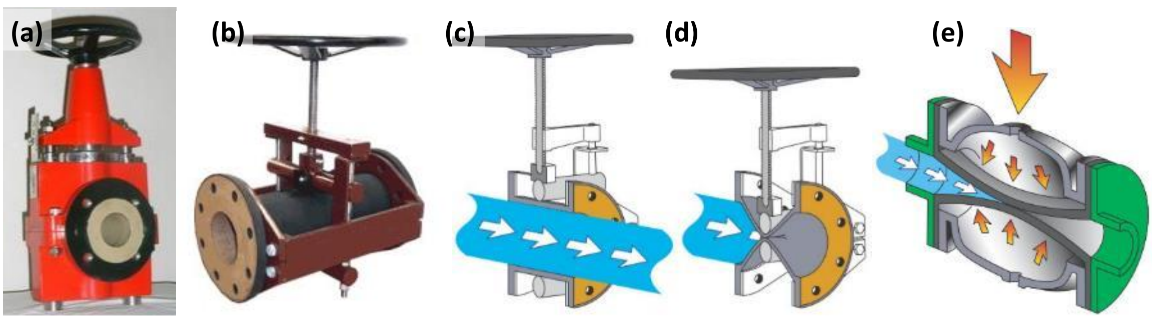


Figure 5-10 – Examples of pinch valves (a) Rhinoflex EN Series (Braeco, 2015), (b) EVR 1100 High pressure (Metaval, 2015), EVR 1100 valve in (c) open and (d) closed condition, (e) EVR AJ pneumatic pinch valve.

Standard pinch valves are typically used for sewage or abrasive liquids where standard valves may be damaged by the flowing material. Despite the fact they rely on a flexible membrane they are also quite capable of handling high pressures (105 m and 35 m for EVR 1100 and EVR AJ models respectively in the 12” size). The cost of these valves is of similar or greater magnitude than cast iron knife valves and they are therefore not suitable for this project. However, a custom made valve with the same mechanism may be more suitable for automation than the standard gate valves used by the industry.

5.3.6. Potential ideas for fluming valves

The significant costs associated with traditional valves encouraged this project to think outside what is currently used in industry. Unfortunately, this work has not yet resulted in any clear practical options as alternatives to existing valves. Some examples of these conceptual ideas are given below.

5.3.6.1. Actuated fluming clamps

The most common and cost-effective means of temporally shutting off the water flow in a length of fluming is through the use of fluming clamps as shown in Figure 5-11 to perform the same action as a pinch valve. Consider a length of fluming with 100 cups being fed from one end. The farmer may place the clamp at the 50 cup mark, and irrigate the first 50 cups, then open the clamp supplying water to the remaining cups while manually replacing each one of the first 50 cups with a blank cup. Alternatively, a field may be set up with risers positioned with 100 furrows between each riser. The farmer may position a clamp at the midway point and supply water from one end at a time to irrigate one half of the furrows, in a different irrigation they could choose to move this clamp to the 30 cup mark so that they can irrigate 30 cups from one side at a higher rate and the remaining 70 cups from the other side at a lower rate.

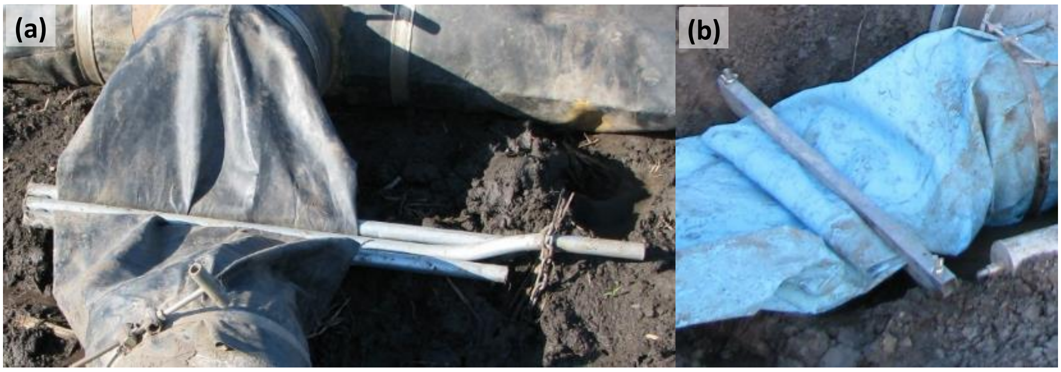


Figure 5-11 – Manually operated fluming clamp (a) lever with chain catch (b) bolted type

It was proposed that a modified clamp actuated using a linear actuator could be used in the system, hence negating the need for expensive butterfly valves and their associated actuators. This idea was explained to the grower steering committee who did not think this approach would work due to the susceptibility of the fluming to failure. The action of closing the clamp puts extra stress on the low grade fluming and may pull the fluming axially, potentially pulling it from the adjacent connection to the riser. When clamps are manually closed the farmer can do so carefully and observe any problems, if this was automated then a failure might go unnoticed until it is too late.

This approach still may be a practical option if the section of fluming immediately around the clamp is replaced with a higher grade material with more flexibility. Some farmers already use a different, higher grade material in the few metres adjacent to valves in problem areas where failure of the traditional fluming frequently occurs, as was observed on one of the outlets at the Pozzebon property.

5.3.6.2. Internal fluming valves

Another alternative to existing valves is the use of specially designed internal valves built into the fluming. This was originally envisaged as a means to start and stop sets along the length of a long length of fluming where the field does not have regularly spaced risers. Sown into the wall of the fluming would be an air bladder which when inflated would block the water flow to that part of the pipeline and when deflated would allow water to pass into that length of fluming. The design could also be reversed where inflation of a circular collar would open up a length of fluming while deflating the collar would block off that part of the pipeline.

This same principle is the basis of duckbill valves (Figure 5-12) which are an alternative to traditional check valves where the rubber duckbill is inserted into the pipe and permits water to flow in the direction of the end of the bill but will immediately close up if the pressure differential decreases to zero or reverses.

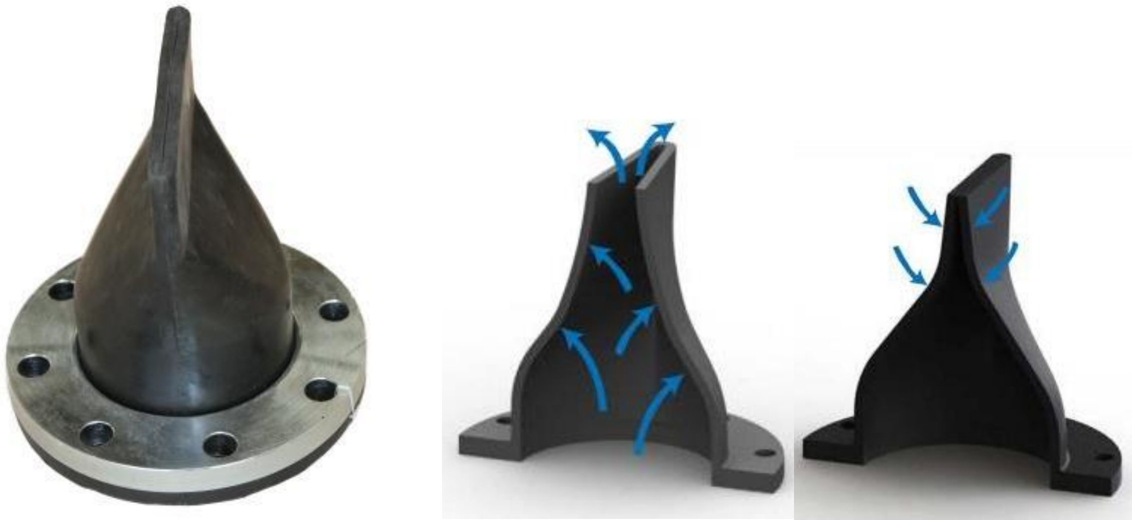


Figure 5-12 – Duckbill valve (ProcessSystems, 2015)

Another option for internal valving is the construction of a bi-walled or dual walled fluming. Here the outlets would be pre-formed into the wall of the fluming pipe (as opposed to being installed in the field). The pipe contains an internal wall which is attached to both top and bottom of the fluming cross section and can lay flat against either half side of the fluming (i.e. cross section length of ½ the pipe circumference). When the internal wall is pushed against the headland side of the fluming, water is allowed to flow through the outlets. When the wall is pushed against the field side, all the outlets are blocked. Use of this bi-walled pipe would require either specially designed valves or a version of the internal pneumatic valve described in the previous paragraph.

The low-grade plastic fluming commonly used by the industry may not be suitable for these internal valve structures. As a result, it is likely that these options would increase the cost of the fluming significantly compared to the existing low-cost fluming commonly used in the sugar industry.

5.4. Actuators

Automatic control of the irrigation system requires a reliable means to open and close the chosen valve. The actuator is the device which applies the force or torque required for this operation. There are two broad types of actuator; linear, where a rod moves in a linear fashion to apply a pushing or pulling force, or rotatory actuators, which apply a rotating motion or torque.

5.4.1. Electric Linear Actuators

Linear actuators typically consist of a motor, toothed gear and threaded rod. There are a large range of load ratings available, for example SKF supply 12V versions ranging from 500 – 6000 N with stroke lengths of 102 – 601 mm. Most actuators include some form of limit switch to avoid any damage to the movement. With additional costs, some have the option of position feedback and therefore control of the positioning rather than simply on or off. There are a range of options regarding the movement speed, with higher speeds typically involving higher cost and increased DC current.

Linear actuators can be used to directly push or pull the valve movement, such as for a slide or knife valve, although the forces required are large. More realistically, they can be used to control valves through use of a lever arm such as the simple example shown in Figure 5-13. This schematic was further refined during the implementation of the project at the sites.

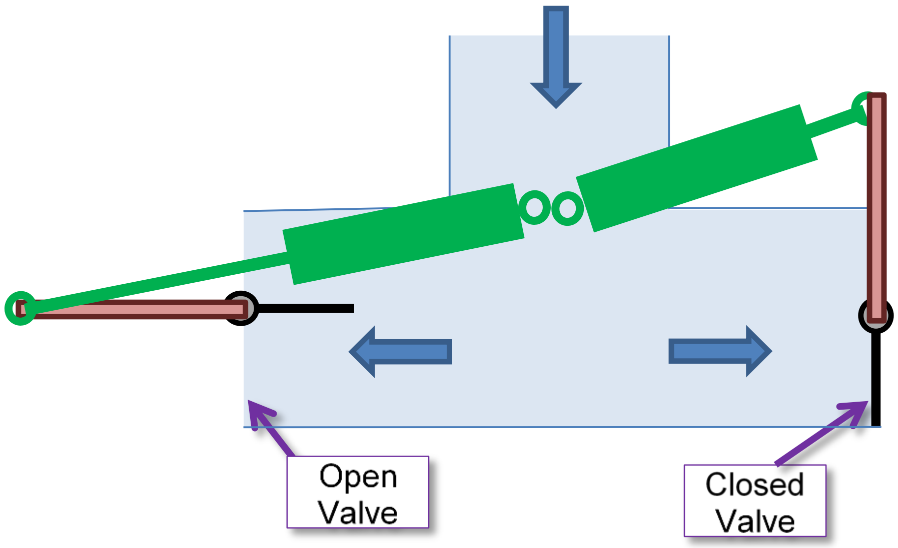


Figure 5-13 – Potential connection of linear actuators to butterfly valves

Linear actuators are manufactured by a large number of suppliers and are available in a range of different models and sizes. Figure 5-14 gives examples from three popular actuator suppliers.

Figure 5-14 – (a) LINAK LA25, (b) SKF 500N CAHB-10 (RS-Online, 2015), (c) Firgelli Heavy Duty (Firgelli, 2015)

Some example prices and specifications are shown in Table 5-7, note that many of these actuators are available in other strokes (displacement length) and forces. There are also a large number of actuators available from international sellers through web sites such as Amazon or EBay for small cost. LINAK actuators are possibly the most common make of actuators used in the irrigation environment and are routinely used in the automated riser outlets and bay gates in border check irrigation. The prices for LINAK actuators of $600 and $1200 are higher than most other options in Table 5-7, which may reflect their relative durability. For example, the LA35 is rated as IP69 whereas the literature available for the less expensive actuators does not make any environmental protection claims. The MODBUS LINAK actuator option includes position feedback and more advanced control over movement and power draw. These prices will fluctuate widely depending on the quantity ordered and the US/AUS exchange rate.

Table 5-7 –Example linear actuators and prices

Model	Stroke (mm)	Force (N)	Price
SKF CAHB-10 12V	100	500	$393
SKF CAHB-20 12V	300	500	$413
SKF MAX3 24V (note that there is also a 12V version)	300	8000	$718
Warner K2G20	300	5338	US $300
TSINY (eBay)	100	1400	$100
WindyNation Lin-Act1-12	300	900	US $70
WindyNation Lin-Act1-12	400	900	US $75
Firgelli FA-240 S-12 Light Duty	300	900	$140
Firgelli Heavy Duty	300	1800	$150
Firgelli Heavy Duty IP66	200 - 400	900	US $240
Firgelli Heavy Duty IP66	380	10,000	US $620
LINAK LA35 with MODBUS	300	6000	$400
LINAK LA35 (price for 300 mm) (factory price)	100 - 600	1000 - 6000	$380
LINAK LA36 (price for 300 mm) (factory price)	100-999	500 – 10,000	$450

The general rule with these actuators is that the actuation force decreases as the stroke length increases. For example, with the LA35 the maximum force of 6000 N is possible with the 300 mm stroke while the same model with a 600 mm stroke will be limited to 1000 N. Each model also has a range of prices depending on the stroke and force requirement but price is not directly related to either. For example, the least expensive version of the LA35 is the standard 300mm stroke which happens to have the highest force for this model.

5.4.2. Electric Rotary Actuators

Butterfly valves can be easily controlled by use of a quarter turn actuator (Figure 5-15) which with the appropriate gearing can be actuated with a low wattage electric motor. Most of the options in this category will rotate a maximum of 90 degrees or will stop once the torque increases. An optional feature is for position feedback indication which could be used to regulate valve opening. For example, Burkert valves may be supplied with options for either Potentiometer feedback or analogue feedback (voltage or current).

Figure 5-15 – Rotational actuators (a) SA 003, (b) SA005 & SA009 AcroTorq actuators (Acrodyne, 2015), (c) Burkert Type 3005 (Burkert, 2015), (d) OM-2 Actuator (ProcessSystems, 2015)

Table 5-8 provides some example prices and torque ratings of a selection of available models. Rotary actuators are specified by a nominal torque value, for example in the AcroTorq models the last digit refers to the torque in tens of Nm. Some manufacturers provide valves with the actuator already attached but in other cases the designer must take care when selecting the actuator. In section 5.3.1, Table 5-4 provides a list of recommended actuator torque for several different models of butterfly valve. The recommended torque values for 300mm (12") butterfly valves range from 226 Nm to 624 Nm which eliminates the models shaded in grey. As a result, suitable actuators capable of controlling butterfly valves are in the $2,000 range which is much higher than the linear actuators listed above.

Table 5-8 –Example rotational actuators and prices

Model	Torque (Nm)	Price
SA003 AcroTorq actuator	30	$313
SA005 AcroTorq actuator	50	$432
SA009 AcroTorq actuator	90	$534
NA009 AcroTorq actuator	90	$1007
NA019 AcroTorq actuator	190	$1378
NA028 AcroTorq actuator	280	$1,431
HQ30 24V Actuator	300	$1,618
OM-3 12V Actuator	150	$1,525
OM-4 12V Actuator (for 250-300 mm Butterfly)	400	$1,980
OM-5 12V Actuator (for 250-300 mm Butterfly)	500	$2,400
Pentair Biffi Icon 02 500Nm 24V for 200 – 300 butterfly	500	$1,800
EA42 24V actuator	100 (250 peak)	$2,151

The OM series actuators (Figure 5-15.d), manufactured by Sun-Yeh industries are rebadged by a variety of suppliers including Process Systems (Valveonline), HMA Valveco, AAP industries, Honeywell, Pipelinedynamics and Armstrongflow. Most of these actuators are available in a range of different AC and DC voltages (12 V, 24 V, 110 V, 240 V), while some of the higher torque models are not available in 12 V. The high torque requirements means that these valves have high currents, for example the OM-4 and OM-5 contain a 180 W motor with running currents of 12 A and 13 A respectively. These high power requirements will be an issue for any valves not located close to a mains power supply. To further complicate the matter, some of these actuators contain a heating element to prevent condensation in outdoor environments. The problem is that these heating elements will have a continuous current draw which would be an issue if wishing to power the valve with solar panels and batteries.

5.4.3. Pneumatic Actuation

Pneumatic actuation is preferred in many situations due to the relative low cost but superior force or torque that can be applied for a given size and weight. Use of these actuators requires a high pressure air supply and air-line which can be a problem in field conditions. There are two relevant types of pneumatic actuators, linear actuators and rotational actuators. A major advantage of pneumatic actuators is the high duty cycle, most pneumatic actuators can be operated continuously without any issues whilst electric actuators have a lower duty cycle (e.g. 20-25%). This is not an issue when used for irrigation automation as normally the valve is only moved twice in a single day.

Linear Pneumatic actuators (e.g. Figure 5-16 (a)) consist of a simple pneumatic ram which may be bidirectional or include a spring return. Spring return valves are difficult to achieve with electric actuation. Neglecting losses, the maximum actuation force is simply a function of the cylinder bore size and air supply pressure.

Figure 5-16 – (a) Linear actuator for Keystone knife valve (Pentair, 2015), (b) Linear actuator for Valtera slide valve (Valterra, 2015), (c) Burkert 2-way butterfly valve with pneumatic actuator (Burkert, 2015), (d) BFD double acting pneumatically actuated valve (ProcessSystems, 2015)

Rotational pneumatic actuators (e.g. Figure 5-16 (c)) operate in a similar manner to their electric equivalents but are generally more cost effective and compact. These valves may be either two-way (double acting) where they can be driven both open and shut using air supply or can be spring return where they are held closed by a spring and air pressure must be maintained to keep the valve open. The spring return is useful for systems were the valves need to be shut in the event of power failure, it would not be particularly useful in the case of irrigation because of the need to maintain air supply continuously. 2-way valves would require two separate air lines per actuator or solenoid valves at the valve in order to switch the direction of the air.

The BFD valve in Figure 5-16 (d) retails for $1,660 which is approximately half that of the equivalent sized electrically actuated valve. Pneumatic actuators tend to operate very quickly compared to electric actuators which will result in increased surging and risk of water hammer. If pneumatic systems were to be used in surface irrigation, further investigation would be required to make sure that the opening and closing speeds could be controlled.

5.5. Automation Hardware and Software Systems

While it is true that there has been limited work conducted in the area of furrow automation in sugar, there are however several examples of application of automation systems for other industries or irrigation systems which can be adapted for the sugar context. The main components of these systems include:

- Software and data storage
- Telemetry system
- Infield sensing hardware
- Infield control hardware

Each of the examples investigated has employed different approaches to provide solutions for these components. The following section aims to summarise and review the relevant technologies.

5.5.1. Current and Previous Systems in Sugar

There have been a number of attempts to automate furrow irrigation in the sugar industry, two notable examples are the WaterWright project and the Game Changer project.

5.5.1.1. WaterWright Project

The most notable example of automation of furrow irrigation in the sugar industry is a demonstration trial conducted in the Burdekin between November 2009 and August 2010. This project involved the integration of a number of existing components to instrument one demonstration field.

The valves and actuators were supplied by Australian Valve and Filter Industries. Two different actuation options were tested; electric actuation and pneumatic actuation. It was concluded that the pneumatic valves were the cheaper option; however, discussion with local farmers suggests that the pneumatic option used in that trial did not work correctly because of the under sizing of the air supply line and long distance between the air source and the control valve. The electronic control and telemetry system were supplied by WiSA, however it appears that the control valves were hard wired to the main unit hence avoiding any need for telemetry at the valve.

Table 5-9 –Components of WaterWright Automation (WaterWright, 2010)

Component		Cost	Details
Control Software	WiSA	$300	
Radio Base Station	WiSA basestation	$2,440	For connection to farm PC
Butterfly Valve (electric)	Valve	$690	Per valve
	Electrical Actuator	$2,200	Per valve
	Control Wire	$365	For 220 m
Butterfly Valve (Pneumatic)	Valve	$690	Per valve
	Pneumatic Actuator	$1,374	Per valve
	Air line	$440	For 440m
In-field Feedback Sensor	Aquaspy Capacitance Probe	$845	
	WiSA Node and Solar Panel	$1,950	
	Cable	$180	
Compressor	Small electric air compressor (for Pneumatic)	$300	One compressor required
Pump Unit	Pump control node and failsafe	$3102	

Those shaded in grey are for the pneumatic system.

In this study, the soil moisture reading at 20 cm was used as the trigger for valve shutdown. The probe was situated close to the end of the field and was connected by cable to a wireless node at the tail-drain. There were some issues with this cable being damaged by vermin. With the 20 cm depth, this would mean that water would be flowing at that point for 10-20 minutes before it was registered by the probe. There were some issues with using the soil moisture probe as a trigger for some of the early irrigations because the advance was not uniform between furrows. The run times for the automated irrigations ranged from 13-14 hours where under manual operation these times would be 15-16 hours across the 20-22 irrigations in the season.

Only limited data was provided (WaterWright, 2010), however this data permitted an estimation of the depths applied and lost as shown in Table 5-10. The efficiency of both trials is very high (>90%) although the flows are low and run times are long. This low loss indicates that this soil has low permeability compared to most soils in the district. It is anticipated that the efficiencies would be lower and potential savings would be higher if the same trial was conducted on other soils.

Table 5-10 –Water use in WaterWright Trial (Calculated from data within WaterWright, 2010)

	Before Automation	With Automation
Cup Flowrate (L/s)	1.2	1.35
Run Time (Hrs)	16	12
Depth applied (mm)	41.9	35.3
Depth Required (mm)	44	44
Depth Lost (mm)	3.8	1.4
Seasonal Application (ML/ha)	9.22	7.78

5.5.1.2. Game Changer Project

The Game Changer project involves a demonstration site for automation of furrow irrigation which was started in late 2014. The project involves a local group of farmers assisted by Farmacist and NQ Dry Tropics. The work was funded through the Project Catalyst initiative, which in turn is funded by World Wildlife Fund and Coca Cola:

> *"As part of Project Catalyst, some 78 farmers are working to improve soil, nutrient, pesticide, irrigation and storm water management on over 20,000 hectares of farm land"*.

The aim of the project was to provide a low cost option for automation due to the high costs of earlier attempts of automation. The demonstration site is on part of a field owned by Willy Lucas, west of Home Hill.

The project successfully developed a system to open and close a valve remotely and also developed a low-cost advance sensor which could communicate to a radio receiver at the end of the field. The Game Changer project attempted to use components of the MAIT system for telemetry and later investigated use of low cost telemetry developed by Australian Wool Innovation. While the prototype was able to send data and receive commands, the project did not develop the software and control system to be able to reliably control the automation system. There has been no commercial application of the technology developed in this project to date but the efforts of Willy Lucas are ongoing.

5.5.2. Rubicon

Rubicon Water is a Victorian based supplier of automation equipment for channel schemes and surface irrigation systems. Rubicon pioneered the idea of total channel control (TCC) through joint research with the University of Melbourne. TCC involves automated control of large irrigation supply schemes which is only possible through a combination of intensive monitoring and hydraulic simulation. Rubicon manufacture a range of gate structures and supply the control and communication hardware to enable control at the scheme level. A radio or NextG node is positioned at each gate structure and every farm offtake so that the entire system is managed from a cloud based server. This system has been implemented across the entire Goulburn-Murray irrigation scheme, the largest scheme in Australia, and also in a number of other schemes both domestically (e.g. Coleambally) and internationally (e.g. US, Mexico, China).

More recently with the interest in precision surface irrigation, Rubicon like the other companies below has branched into automation of border check irrigation as is practiced in Victoria and southern NSW. Rubicon supplies one universal radio node (Figure 5-17.b) with a 12 V 9 Ah (108 Whr) battery which is capable of connecting to the various control structures and infield sensors. This is the same node which is used throughout the TCC scheme automation. The nodes all communicate via 2.4 GHz ZigBee radio to the nearest base station (Figure 5-17.a), (usually one per property), the base station then communicates with the Rubicon cloud server through the mobile phone network.

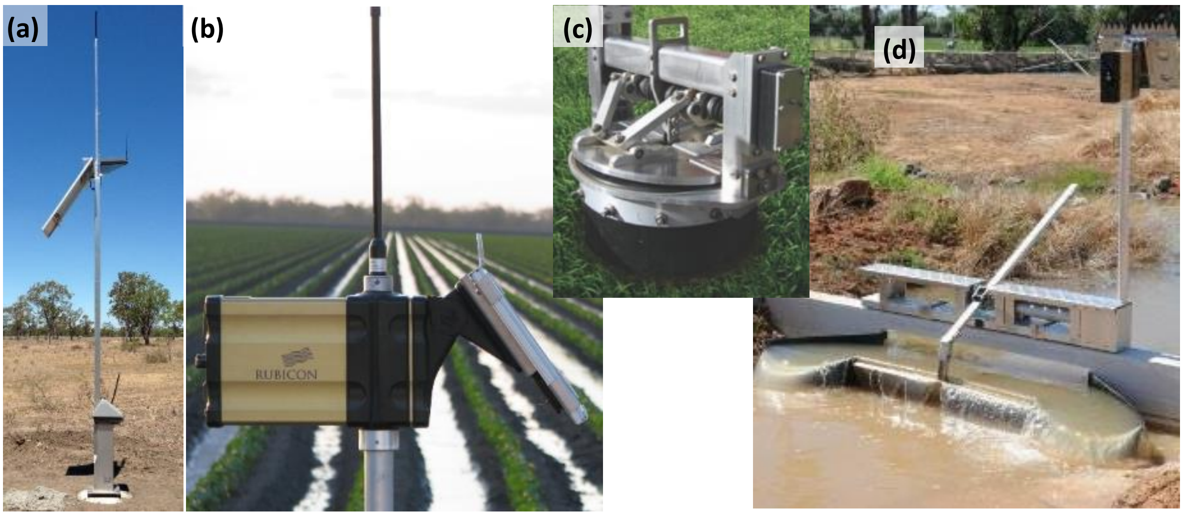


Figure 5-17 – Rubicon components (a) Farm base station, (b) ZigBee Node (c) Drop Gate, (d) Blade valve (Rubicon, 2015).

The most relevant components for automation of furrow irrigation in sugar are the drop gate (Figure 5-17.d), the riser valve or blade valve (Figure 5-17.c) and the in-field water depth sensor (Figure 5-30.a). The blade valve is unique compared to other pipe and riser valves in that the sealing mechanism folds into the pipe and claims to have a lower closing force than other options. In its current form, the blade valve connects to the terminal end of a pipeline and therefore is not currently suitable for connection of fluming. This may be rectified with a new version of the valve in the future.

All data is monitored and control is performed over the internet through the Farmconnect web page as a contrast to WiSA and MAIT which are farm PC based. Farmconnect allows the user to monitor the state of any control structure, water levels and soil moisture wherever these probes are installed. Figure 5-18 shows the map within Farmconnect for a typical dairy farm with automation installed on each bay. Bays in this example are between 0.8 – 2 ha in size, which is approximately half of the size of a typical irrigation block in a sugar field.

Figure 5-18 – Example of dairy farm instrumented with Rubicon automation for border check irrigation.

Farmconnect, like most of the other options, allows the farmer to set up an irrigation timing schedule as shown in Figure 5-19 for a section of the dairy farm given in Figure 5-18. Here the farmer has scheduled a pump to start and a sequence of 11 bays to open and close in turn, each with their own irrigation duration.

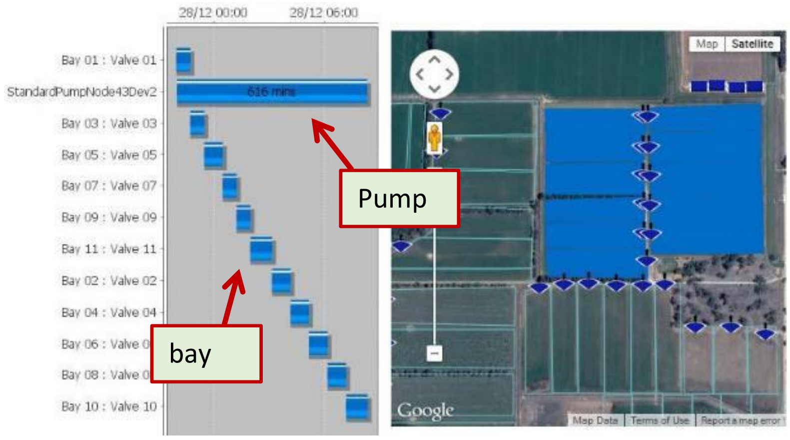


Figure 5-19 – Screenshot of Rubicon Farmconnect irrigation schedule for a dairy farm in Victoria.

Table 5-11 contains preliminary costings for the major components of the Rubicon automation system. Although the T-Valve as used in the cotton automation trial may not be appropriate for sugar, it serves as a good basis for the costing of a modified valve for the risers used in sugar fields.

Table 5-11 –Preliminary costs for Rubicon system (supplier costs as of 2014)

Item	Est. Cost	Comment
Farmconnect base station	$5,250	Usually only one required per property
Farmconnect data cost	$450	Annual + $10 per unit
Outlet node + T-Valve	$2,500	This can control 2 separate actuators
Outlet node + 600mm gate	$2,600	Standard gate used in border check
Water level /advance node	$2,500	Used as feedback to determine shutoff time
Soil Moisture Probe Node	$3,470	Not required for automation
Pump controller node	$2,300	For electric pumps

5.5.2.1. *CRDC Furrow Automation Trials*

Over two summer seasons (2013 – 2015) the NCEA was involved in a project to demonstrate smart automation of furrow irrigation in the cotton industry. There were two sites in 2013-2014 (Moree Telegara and Goondiwindi) and two sites in 2014-2015 (Moree Redmill and Emerald). At each site, there was a single outlet actuator node and one water advance node. Three of the sites were monitored closely in order to evaluate irrigation performance and fine-tune the shut-down trigger.

Large PTB with T-Valve & fluming  	*Moree and Goondiwindi (2013-2014)* • Distributes water evenly • Pipe may be rolled up if required • Flow is controlled by orifice size • Potential risk of valve or pipe blocking with trash • Requires more head than other options
Drop Gate with T-piece  	*Emerald (2014-2015)* • Higher flows than T-valve • Can be connected to fluming for even flows • Care must be taken to size pipe appropriately if fluming is not used
Drop Gate with small PTB's  	*Moree (2014-2015)* • Uniform water distribution • Large number of furrows for each control point • Size of PTBs governs flow • PTBs must be installed level • Requires either a secondary head ditch OR significant slope in channel

Figure 5-20 – Summary of options tested for automation of water delivery to cotton furrows.

A major task in this project was the modification of the Rubicon system in order to accommodate the supply of water to individual furrows. A number of approaches (Figure 5-20) were tested, including the T-valve with fluming, the drop gate with T-piece and drop gate with small pipes through the bank. The most relevant for this project is the T-valve and fluming. This T-valve consisted of a plunger which seals against the intake and when opened supplied water to both sides of the T simultaneously. The fluming was custom-made by Bartlet in order to achieve the required high flows with minimal supply head. The outlets were 75 mm ID reinforced holes, factory cut into the fluming with socks permanently glued around each outlet. As a result, the flow-rates expected from these outlets are almost double that for a large 50 mm fluming cup, achieving 4-5 L/s from less than 300 mm head in the supply channel. This fluming worked well, but at one site the valve failed to close fully when it became blocked with trash and tree branches, a problem which would not be encountered in most sugarcane farm water supplies.

In the 2015-2016 season, a grower at Wee Waa implemented a version of the Drop gate with small PTB, at a larger scale. The layout (Figure 5-21) employed at this field required building a secondary head channel parallel to the original which was blocked off in 310 m long sections. Each of these 310 m lengths of secondary channel contained 155 small PTB pipes buried in the new channel wall, similar to the Moree trial. Water is delivered to each of the 310 m long secondary channels using a 1000 mm drop gate from the main supply. The total cost of this system was close to $1,000 per ha with the major component of this being the earthworks and PTBs in the new channel. The breakthrough with this system was the uniform delivery of water to a large number of furrows (155 pipes) and significant area (18 ha) using a single automated gate.

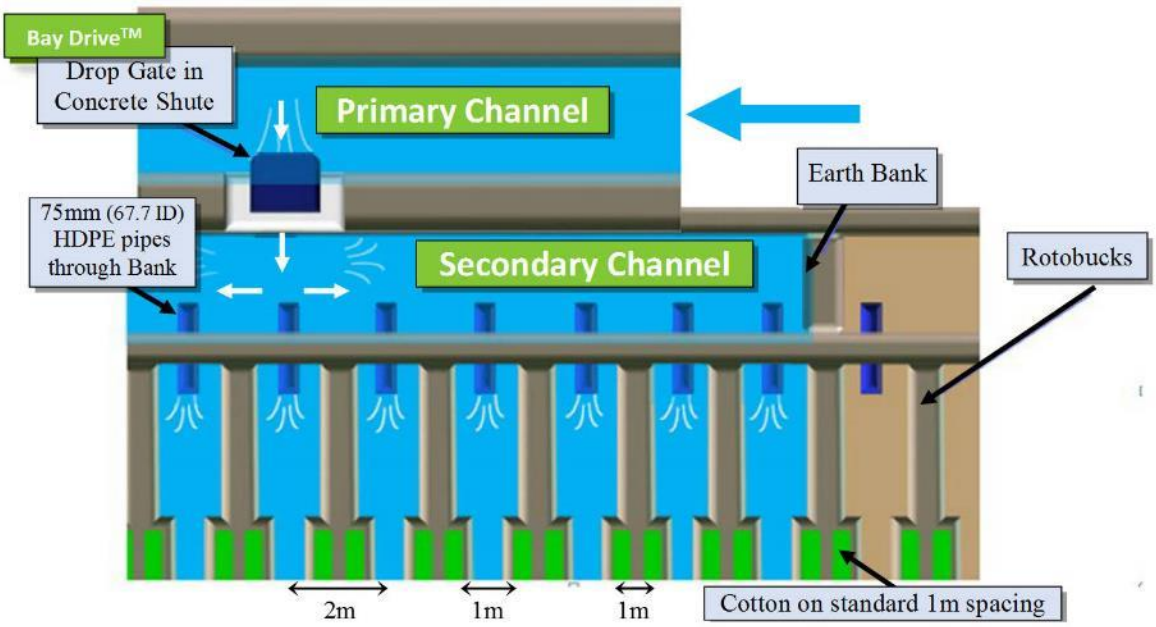


Figure 5-21 – Schematic of blind head ditch and small PTB design used at Wee Waa site.

While they may not be directly applicable to sugarcane field layouts, the CRDC trials can be used to demonstrate how the system costs vary depending on the size of each set. Table 5-12 contains rough estimates of the automation system components for the five fields where the system was deployed. In each case these costs only represent the automation components and do not include any of the modifications which were required to the field layout such as the cost of the fluming at Moree Tel. or Goondiwindi or the cost of installing the small PTB pipes at Moree Redmill or Wee Waa. The total costs have been calculated assuming that 200 Ha has been automated which may represent between 2 to 4 regular cotton fields.

The cost per irrigation set is very similar between the five cases, which makes sense as each set contains a single control gate or valve and end of field sensor. The cost per hectare varies from $1,370 with a set size of 3.72 ha down to $448 per ha for a set size of 18 ha. Therefore, the unit cost of the automation system is a function of the area supplied by each control gate or valve. The same should occur in furrow irrigated sugarcane where irrigation blocks or sets have a wide range of sizes.

Table 5-12 –Estimated costs for Rubicon Demonstrations

Property	Moree Tel.	Goondiwindi	Moree Redmill	Emerald	Wee Waa[3]
Field length (m)	930	1100	850	1200	582
Number of rows in set	40	40	100	52	155
Area (Ha)	3.72	4.4	8.50	6.24	18.04
Cost of inlet structure & advance probe[1]	$5,000	$5,000	$5,100	$5,100	$7,600
Base Station	$5,250	$5,250	$5,250	$5,250	$5,250
Total cost per set[2]	$5,098	$5,116	$5,323	$5,264	$8,074
Total cost per Ha[3]	$1,370	$1,163	$626	$844	[3]$448

[1]Not including the fluming or small PTB's

[2] assuming that 200 Ha is automated and farm has 1 base station

[3] From a trial conducted in 2015-2016, the total cost of all setup including the PTB and new head channel was close to $1,000 per ha.

5.5.3. Observant Systems

5.5.3.1. Observant Nodes

Observant focusses on the nodes and related software while leaving other specialists to focus on the application to local industry requirements. For example, both AWMA and Archards have developed automation systems which rely on the Observant telemetry.

Observant sell three products, the C3, Solo and Pico units. The C3 unit (Figure 5-22) is the standard node with all input and output options. The Solo is a scaled down version of the C3 and is not yet commercially available and the Pico contains the basic communication hardware. The much smaller Pico unit lacks the battery size and power outputs of the other options and is designed to be incorporated inside other devices.

Figure 5-22 – Observant C3 radio node (Observant, 2015)

The C3 (Figure 5-22) unit is the most appropriate choice for switching valves and collecting measurements, these nodes may either contain their own 3G/4G sim or be part of a radio mesh which communicates to the web via a secondary node with 3G/4G. The C3 includes a battery storage of 75 WHrs and a 7-10 year design life. The C3 can be used to control one or more linear actuators, either a

LINAK LA35 or LA36 where these actuators are ordered with the Modbus option. The C3-A version is capable of powering actuators through a 10 A power connector, therefore max power of 120 W.

Observant do not supply these directly but through various local distributors. Two examples are given in Table 5-13 from two different retailers, one of with a tank level sensor and other with a capacitance soil moisture probe. Both units quoted are supplied with the NextG modems which attract an $8 per month data fee. It is assumed that the radio telemetry version has the same unit costs as this NextG model.

Table 5-13 –Estimated costs for Observant components

Item	Est. Cost	Comment
C3 Node with water level sensor and NextG	$1,925	Sold as a unit for measuring levels in a tank
C3 Node with 800mm capacitance soil moisture probe and 3G/4G	$1,863	ETS Envirotek Solutions
C3-A Node for Power to Actuators	$2,116	Capable of powering LINAK Actuators Directly through MODBUS

All devices which are connected to the Observant nodes can be accessed through the Observant Global web portal (Figure 5-23). Similar to other systems, the portal allows users to interrogate sensors or control devices, analyse and plot data and schedule operations. The fact that all Observant nodes use this system permits a stable and reliable platform that each supplier can use without requiring the supplier to develop their own software or maintain their own cloud server. It also means that farmers may have a combination of devices from different suppliers (for example an AWMA gate and a self-installed soil moisture probe) which are all accessible through the same interface.

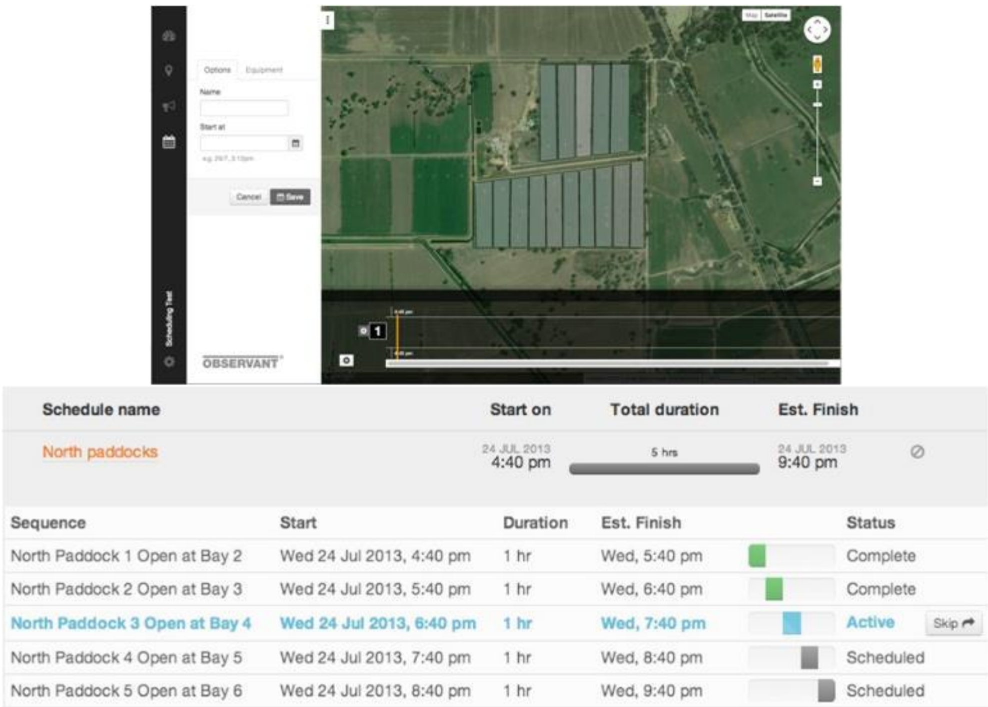


Figure 5-23 – Observant Global web portal (AWMA)

5.5.3.2. AWMA

Like Rubicon, AWMA were working in the channel scheme level before producing systems for on-farm automation. The first generation AWMA On-farm automation system, Aquator (see 5.5.7.1), split from AWMA some time ago but now AWMA offer a new series of devices for automation of border check irrigation under the trademark AIM (Advanced Irrigation Management) which also involves DHI, Observant and Parasyn.

Figure 5-24 – Components of the AWMA on farm automation system (AWMA) (a) I-RiserPLUS, (b) I-RiserPLUS with removable control node, (c) I-Lifter flap gate (AWMA)

AWMA supply two different control mechanisms to satisfy the two most common approaches to deliver water to irrigation bays, the I-Riser (Figure 5-24.a) for pipe and riser systems and the I-Lifter (Figure 5-24.c) for the conventional open channel drop gate. The I-Riser is comprised of a linear actuator (LA35 or LA36) which is connected to a plunger which seals against the end of the vertical riser. The I-Lifter raises and lowers the flap gate through a system of cables and pulleys.

The radio node can be used in two configurations, in a permanently installed mode and a roving mode. The roving mode which is marketed as a low-cost entry level product requires the I-Riser or I-Lifter to be permanently installed at each bay while the roving unit, the top part in Figure 5-24.b, can be easily moved between locations. The principle is that the farmer only requires a small number of roving nodes thereby reducing the system cost. The devices are controlled using the Observant web based portal.

5.5.4. WiSA

The WiSA system (WiSA Irrigation Solutions) differs to both Rubicon and Observant in that the control software is resident on a local PC (for example at the farmer's home) rather than being hosted in the cloud. In this way, the farmer is responsible for all aspects of the system and no data is sent off site. Some farmers may prefer this option as they have full control and responsibility over the system. The farm based approach does limit the ability to operate this system from a remote location or from a mobile phone. One important caveat is the need for each farmer to ensure that the PC is secure, protected from power surges and is regularly backed up to avoid losing configurations and historical data.

In a similar manner to the other manufacturers, WiSA provide a robust solution for automation of border check irrigation through the use of LINAK actuators for opening pipe and riser outlets or lifting bay irrigation gates. The standard approach for WiSA in border check fields is for one node and solar panel for each riser valve; however, WiSA are currently investigating the use of a single WiSA node to control two LINAK LA35 actuators thereby reducing the system costs.

Table 5-14 –Estimated costs for WiSA components (these costs were later superseded by retail costs as given in a later chapter)

Item	Est. Cost	Comment
WiSA Base Station	$2,945*	One required for the whole farm
WiSA Node and Solar Panel	$2,345*	
Pump shed unit	$3,720*	For control of pumps and monitoring flow, pressure etc.

***Costs are based on WaterWright project with 20% inflation**

WiSA is, at the moment, the preferred option on one of the farms and as such they are currently refining hardware that is used in border check irrigation for sugar. The costs provided in Table 5-14 from the WaterWright automation project for the base station and radio nodes should serve as a guide for potential prices with actuation being provided by linear (LINAK) or rotational actuators. Communication between units is through 900 MHz radio which, like the other local radio based systems, requires line of sight between antennas. As a result, WiSA recommend the use of 6m masts for the field nodes in a sugar environment.

Technical details of the WiSA system is provided throughout Chapters 6 and 7. Current prices for complete installed systems are given in Chapter 10.

5.5.5. MAIT Industries

MAIT offer three different systems, the radio controlled, cable controlled and cloud based systems (MAIT, 2015). They also supply a range of sensors (e.g. capacitance, weather, pressure) which are compatible with the nodes below.

The radio controlled system consists of a farm radio base station (iBase Radio IBR) connected to a PC which communicates to all devices and stores data for the rest of the system. The PC runs two different software packages, iNTELLiPump for control of the irrigation system and iNTELLiGraph for monitoring, storing and presenting data. The radios above have a 6km line of sight node to node. There are several different nodes available (Figure 5-25) with different capabilities in terms of inputs and outputs:

- iControl 12-Radio Single – 1 x 12 V solenoid and 2 sensors
- iControl 12-Radio Dual – 2 x 12 V solenoid and 2 sensors
- iControl 1-Radio Single Flood – 1 x 12 V actuator or motor and 2 sensors
- iControl 12-Radio – 4 x 12 V solenoid and 1 sensor
- iControl 24-Radio – 16 x24 V solenoids or 16 pumps
- iData Radio – logging and transmission of up to 9 sensors

The cable controlled system is based on similar components to the radio system (such as the iControl 12, iControl 24 and iData Logger) and the complete system can be a hybrid of radio and hard-wired nodes.

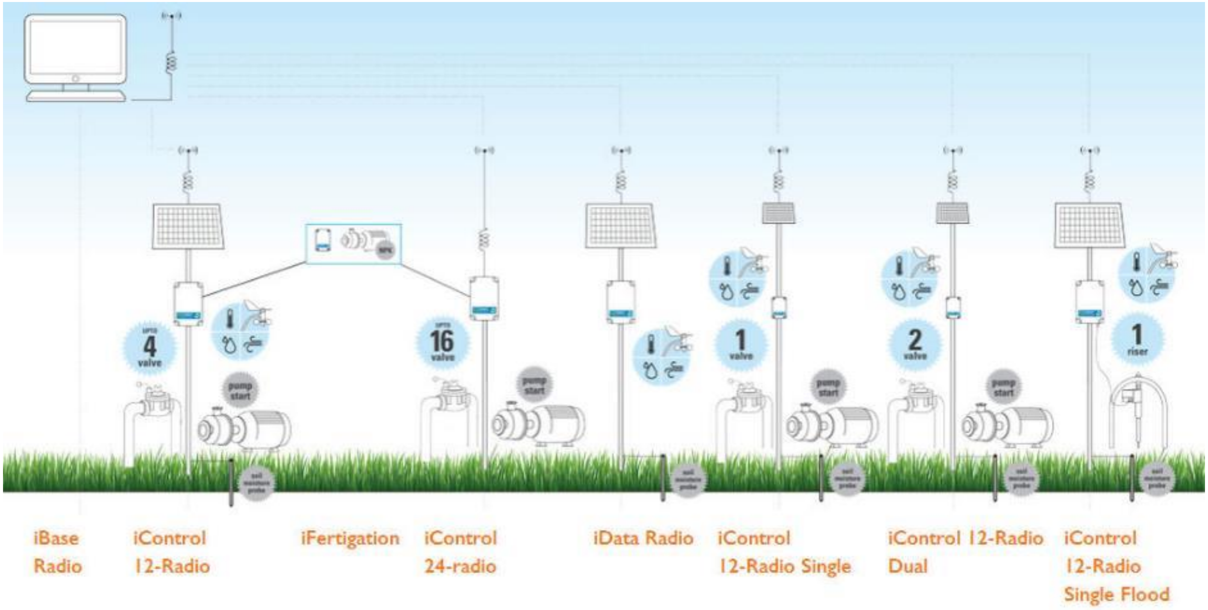


Figure 5-25 – The MAIT Radio Controlled system (MAIT, 2015)

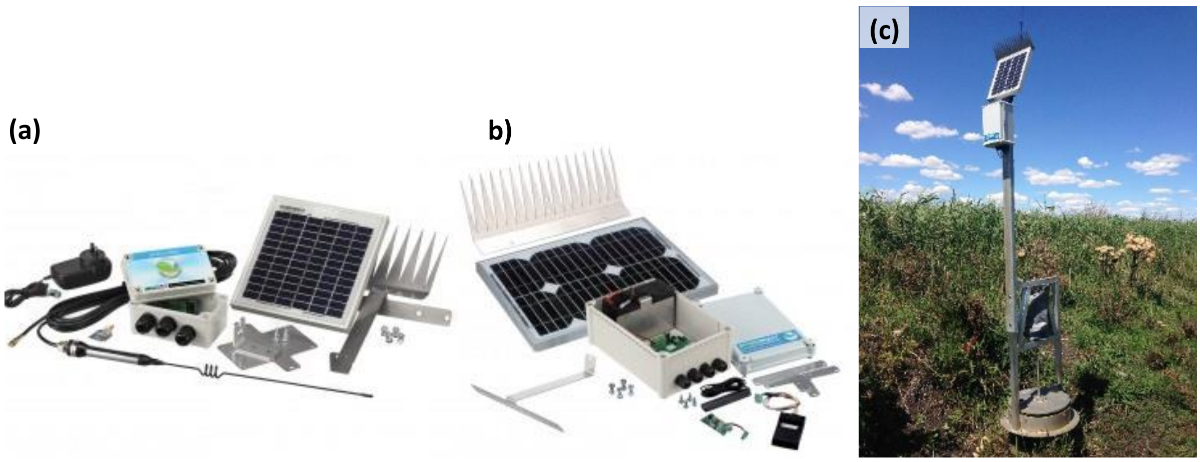


Figure 5-26 – MAIT components (a) iControl 12-Radio Single (b) iData Web Single (c) MAIT riser control system

The cloud based system works in a similar manner to the radio system except that each node communicates to a cloud based server through its own next G modem. The system is controlled via the iNTELLIWEB software which is accessed through a web address and data can be downloaded to a PC for use with the iNTELLiLogger software. The field components of the cloud system include the iData Web (Figure 5-26.b) which has similar capabilities to the iData Radio above (9 sensors) and the IData Web Single which is limited to 2 sensors.

There is also an option for a number of radio nodes to communicate with a single iData WebGateway node which can communicate to the cloud. In that way, a radio system need not be located in close proximity to the farm PC.

5.5.6. Padman

Padman is a notable example of automation system as a contrast to the previously discussed approaches. Unlike other systems which rely on cloud based systems or farm base stations, the Padman system is a field based system where the control nodes talk only to each other or potentially receive signals from a water front detector. The system uses a series of Gate Keepers which are portable nodes (with power supply and telemetry) which connect to a gate control mechanism (lifting arm). The node on the first bay is a Master Gate Keeper (Figure 5-27) which initiates the irrigation, communicates to the other nodes and also can send text messages to a phone.

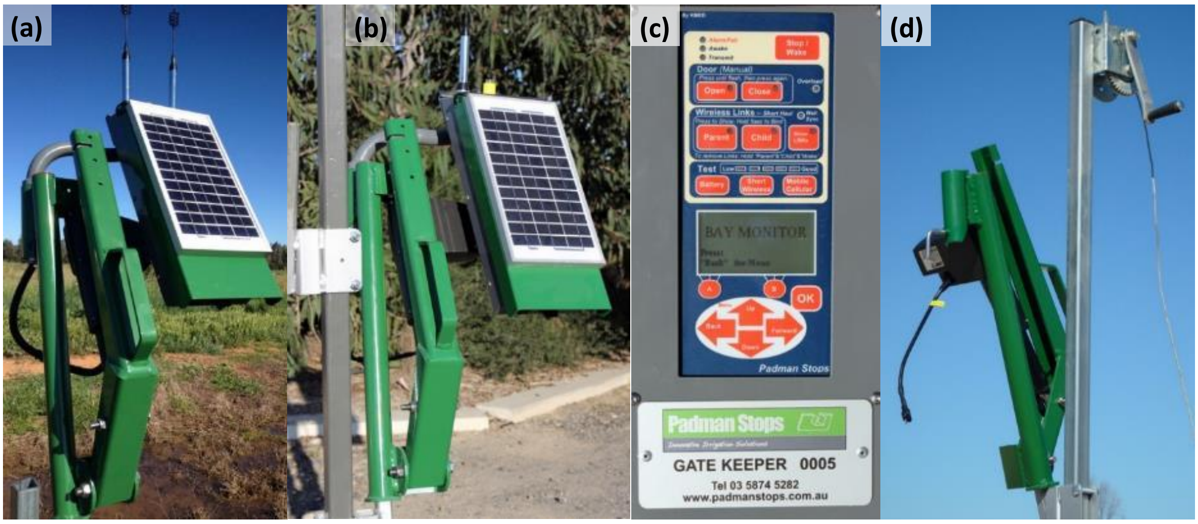


Figure 5-27 – Components of the Padman SamC system (Padman, 2015) (a) Master Gate Keeper, (b) Gate Keeper, (c) Gate Keeper control panel, (d) lifting arm.

The components of the SamC system are listed in Table 5-15, please note that the gate keepers are portable and can be moved to a different position that has the lifting mechanism installed. These prices do not include the bay gate. This lifting mechanism also includes a manual lifter, something that is missing from some of the other electrically controlled irrigation gates. In addition to the SamC feedback system, Padman also manufacture a timer based electric gate opener/closer, but use of this would require the farmer to independently start the next bay or shut-off the water.

The operation of the complete system can be described in the following steps:

(1) The farmer starts the irrigation using the Master Gate controller in bay 1.
(2) A Bay Watcher somewhere in bay 1 detects the water and sends a signal to the Master to close bay 1.
(3) The Master closes bay 1; tells bay 2 to open and optionally sends a text message.
(4) Bay 2 opens and irrigates for the same time as bay 1 or optionally can be paired with its own Bay watcher (e.g. if the bay is different length or width).
(5) Bay 2 closes and informs the Master which sends the signal to the next bay.
(6) Process repeats until last bay is finished, whereon the Master will send a text message to farmer.

Table 5-15 –Estimated costs for Padman System

Item	Est. Cost	Comment
Master Gate Keeper	$2,465	One required for a series of bays
Gate Keeper	$2,225	Standard unit with telemetry and control
Bay Watcher	$1,075	Portable water front monitor
Lifting Mechanism	$675	Lifting mechanism which can accept the portable gate keepers.
Portable Timer based gate lifter	$1,655.00	Standalone timer based control
Concrete Bay outlet	$485 -$725	Cost depending on size (3ft - 8ft)
Estimated cost per bay*	$1,180	
Estimated cost per Ha*	$788	

***Assuming a farm with 40 x 1.5 ha bays, 1 Master Keeper, 7 Gate Keepers and 2 Bay Watchers. Costs do not include the concrete gate**

5.5.7. Others

5.5.7.1. Aquator

Aquator™ is a system first developed by AWMA for the automation of border check irrigation systems. This system is no longer owned by AWMA and is available through G&M Poly (G&MPoly, 2015). Aquator uses a base station connected to a PC which can communicate via VHF across 8 km or 30 km (depending on transmitter) and nodes installed at each control structure. In bay irrigation, the nodes are connected to linear actuators at each bay gate. In 2008 this system was also capable of controlling pumps and monitoring bore levels. Although the Aquator system has not been considered in this project, it is useful to review the only known application of this system in furrow irrigation.

In 2009 this system was installed in a furrow irrigated cotton farm near Moree (Williamson and Wigginton, 2010) as part of a demonstration of new technologies. In this case the system was used to open and close 12" PTB (pipe through bank). The trial consisted of a field 256 m wide and 1000 m long that was irrigated by 16 PTBs each of which was fitted with an Aquator node (Figure 5-28). Cotton farmers typically use siphons (poly pipes 4m in length and 1" – 3.5" dia.) for each irrigated row which involves a high labour requirement. A number of irrigators replaced the siphons with larger PTBs servicing a number of furrows, however this suffered from low uniformity with most of the water being directed to a few furrows out of the set rather than being evenly spread. For the automation system, fluming was used to deliver water to the furrows, to replicate the existing siphon flowrate of 6.4 L/s the system required two standard outlets per furrow.

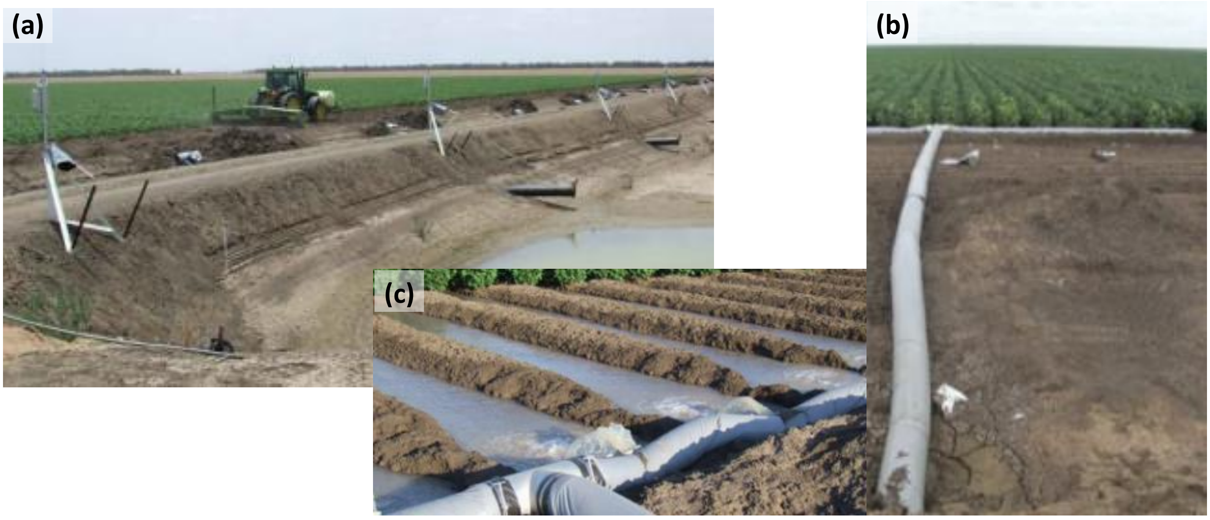


Figure 5-28 – (a) Supply channel and automated flap gates, (b) fluming connecting PTB to field, (c) fluming with outlets (Williamson and Wigginton, 2010)

In this trial, the cost of the automation system was $1,300 per ha for the fluming, and PTBs a further $400 per ha. Each PTB had its own node and linear actuator and serviced 8 irrigated furrows (16 plant rows). Hence the cost per node was $2,080 plus $640 for fluming.

5.5.7.2. Emerging systems

The technology sector rarely stands still for any period of time and as a result any review of automation systems quickly becomes redundant as new technology becomes available. Historically most systems relied on simple systems sent over a radio network but new technologies such as the Long Range Wide Area Network suite of systems (LoRaWAN) are set to revolutionise the cost and quantity of data which can be sent wirelessly across the farm. Improvements in Satellite communication and mobile network coverage are also offering up significant potential for use on farm.

The systems described above do not represent all of the relevant technologies but they do represent a wide spread of the commercially available systems as of 2015 when the project was investigating potential hardware for the demonstration sites.

5.6. In Field Sensors

There is a range of sensors available for monitoring the irrigation progress, soil or crop. This section will focus on those sensors that are relevant to the automation system for furrow irrigation.

5.6.1. Advance sensors

5.6.1.1. Contact Sensors

One of the most appropriate and, conveniently, also the most simplistic approach to monitor the irrigation is to measure the time taken for water to reach a specified location in the field. During a full evaluation of the irrigation, water advance is measured at multiple (5-6) locations along the field length and across multiple adjacent furrows. The IrriMATE™ advance sensors (Raine et al., 2005), which are routinely used in Australia for evaluation purposes, measure up to eight adjacent furrows and record the time at which water reaches the designated position in each furrow. These sensors must be manually placed in the furrows and reset just prior to each irrigation, they also have no ability to communicate with any other device. For these reasons, the traditional advance sensor is not of any use for the automation system.

One approach is for the advance detection sensor to be standalone, and send signals to the irrigator as to when the water has reached the end of the field or some other predefined distance. The most simplistic form of these devices is independent to any automation system and instead simply sends an SMS message to the irrigator when the water reaches the device, for example Figure 5-29. This device still requires the farmer to manually switch to the next bay or set.

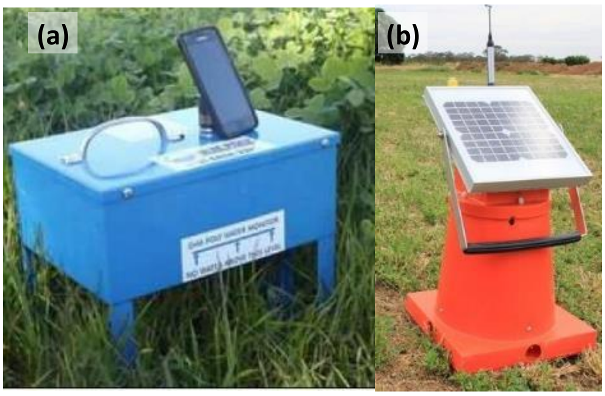


Figure 5-29 (a) G&MPoly water monitor (G&MPoly, 2015), (b) SMS Chatterbox Bay Monitor (Padman, 2015)

The performance of these simple advance sensors in the sugar situation is untested. The presence of wet trash may prevent these sensors from successfully detecting the presence of the water advance, and it is possible that they may report false positives or never indicate that the sensor is in a dry state when wet trash blocks the sensor. Both of the examples given in Figure 5-29 are designed for bay irrigation and will block the path of water flow if installed in an irrigated furrow, however it should be possible to modify the design to suit sugarcane.

Table 5-16 –Costs for selected infield sensors

G&M Poly SMS Water Monitor (G&M Poly)	$1,650
G&M Poly UHF Water Monitor (G&M Poly)	$1,540
G&M Poly UHF receiver (G&M Poly)	$1,540
Padman SamC – Bay Watcher (for use with Padman Gates)	$1,075
Padman SMS Chatterbox Bay Monitor (standalone Bay Watcher with SMS signal)	$1,675

5.6.1.2. Water depth sensors

Water depth is a key piece of information for channel control and can also be important within the field. There are three main techniques in order to measure depth, ultrasonic, capacitance and pressure transducers (PST). Ultrasonic sensors rely on an emitter and detector which is positioned above the ground/water surface and through timing the sound reflection can estimate the distance. Ultrasonic sensors are relatively inexpensive and are easy to calibrate. Capacitance style sensors pass current through a wire and detect the change in capacitance due to the material around the wires. The capacitance probe is partly immersed in water and the range is determined by the length of the wires. PSTs are normally used to measure heads in pressurised systems but are also available in configurations which are sensitive to small changes in water level.

There are several options for water level monitors across the providers of automation equipment, such as the Floodtech sensor Figure 5-30 (a) which is an ultrasonic sensor housed within a protective metal tube.

Figure 5-30 – (a) Rubicon Floodtech sensor node (b) Intech WT-HR capacitance probe

Water depth is an essential source of information when attempting to evaluate border check irrigation because of the interaction between pasture condition and water depth. The same level of importance has never been proven in furrow irrigation although the depth information may be still useful. Water depth measurement provides a water front sensor which can reliably detect water arrival and recession and does not have the issue of simple contact sensors which may be set off or fail to reset back to dry if the electrical contacts are still wet at the end of the irrigation.

Water depth sensors also provide a potential means of assessing the supply head for estimating flowrates in the fluming situation as an alternative to using electronic pressure transducers. They could be mounted within the supply cylinder but this would require an assessment of the loss between the cylinder and the fluming of interest.

5.6.1.3. Other possibilities for advance measurement

The major shortcoming of existing advance sensors for automation is the fact that they are only able to monitor a single furrow. A key message from previous work by the NCEA in furrow irrigation of cotton was the difficulty in relating a single furrow, in that case water depth, to the behaviour of the entire field. In that trial, the water depth sensors were carefully located in a representative furrow which was neither the slowest or fastest furrow in the irrigation set. The high control on inflow rates in that trial also meant that the variation in advance rates remained consistent throughout the season but there is no guarantee that this could be replicated for other fields.

All the commercially available techniques rely on a sensor, power supply and communications device located in the field at the location of the sensor. This is an issue for any crop as it may require temporary removal of the device prior to any in-field operation. Locating sensors in the field also runs the risk of animal damage. Sugarcane poses a greater challenge due to the larger crop size and high biomass which may compromise the radio signal or require the use of high radio masts.

One alternative is the use of remote sensing to detect water advance although at this stage there is no commercially available device which is able to perform this function. McCarthy (2004) used a visual camera mounted on a 5 m mast at one end of the field to record images and then developed an image processing algorithm which was able to detect the water front and calculate the distance of the water front. More recent work at the NCEA is investigating the use of flying drones to collect these images. Visual image capture and processing show promise, however this technique is currently restricted to the early stages of the crop before canopy closure, and to daylight hours.

One alternative remote sensing technology is the use of thermal imaging or thermal sensors. It is hypothesised that the irrigation water will have a different temperature to the surrounding dry soil which should have a higher temperature during the day. Secondly, it is hypothesised that the presence of water has a cooling effect on the crop microclimate. It should be possible to detect both of these temperature changes using thermal imaging. Preliminary tests of a thermal camera in April 2015 on a newly planted cane crop (1 week after planting) were promising. The advance front was clearly detectable during both daylight hours and night time hours from more than 100 m away from a camera held at 1.6 m above the ground. Further development is required before thermal imaging is a viable option for advance detection.

5.6.2. Soil moisture probes

Most automation systems have the option of inclusion of a soil capacitance probe, either manufactured by that company or by a third party. Use of these devices is common throughout broad acre cropping industries in Australia, however the high cost (>$2,000) associated with the probe and telemetry systems mean that farmers usually only have one or two probes installed across the entire farm. Soil moisture probes are typically used to assist in the process of irrigation scheduling. They may also be useful for the detection of the water advance, however they suffer from the problems that they could only sample a single furrow and that there may be a lag time between water arrival and soil moisture detection.

While soil moisture probes may not be the best option for advance measurement, the ability to provide soil moisture data in addition to the advance time means that they may be a desirable addition to any automation system. At the very least, the automation system should have the ability to accommodate soil moisture sensors even if they do not have any direct link to the control of the irrigation itself. If the advance feedback system uses an automation node such as the Rubicon unit or Observant C3, a soil moisture sensor can be added at minimal extra cost as the same node can connect to a number of sensors.

One notable example is the EnviroPro soil capacitance probe which is sold in combination with the Observant C3 probe for less than $2,000 (Table 5-13) which is a similar retail cost to the Observant node alone. The same sensor is also used within the MAIT on-farm automation system.

5.6.3. Flow and Pressure Measurement

Flow rate is by far the most important determinant of the volume applied, irrigation time and speed of water advance. For this reason, flow rate measurement is a crucial part of any evaluation of irrigation performance. Flow rate monitoring can also serve as a diagnostic tool to quickly establish if all valves are opening and closing as desired, and also to check for fluming failures.

Flow measurement at the individual furrow scale and or set scale is useful for system evaluation but excessive for the purpose of day-to-day operation. The most appropriate way to capture flow information in an automation system would be to install an EM-flowmeter in the delivery line of the pump. The proximity of the flowmeter to the pump means that both could communicate through a single radio node.

Pressure and flowrate are linked in any piping system, for a pump an increase in flow always coincides with a drop in the head (or pressure) supplied by the pump. The reverse is true for flow through pipes and from the fluming through the outlets; an increase in flow is always associated with or is caused by a higher head differential. Electronic pressure measurement using PSTs tends to be more cost effective than flow-meters although it is often difficult to infer system behaviour from pressure alone. The relationships between fluming head and outlet flow are well documented (Table 5-2) and can be refined through field measurements. The prices for PSTs vary considerably depending on accuracy, durability and output signal with prices ranging from $400 – $2,000.

Accurate pressures may have additional importance where growers wish to operate valves in partially open condition and have those valves respond to changes in the supply head and/or flow. Unfortunately, this application was not investigated within the timespan of this project.

5.6.4. Other Components

Cameras are an example of a low-cost device which may be very useful in providing diagnostic information regarding operation of the system. The only caution is that cameras can involve a large data requirement, depending on the resolution and frequency of the image captures.

Weather measurement can be integrated into the automation system. Rain gauges are particularly useful, particularly for pressurised systems as small amounts of rainfall can have a significant impact on the timing and volume of the next application or even to cease the irrigation while it is underway. Subsequently some suppliers (e.g. MAIT) already supply weather instruments such as rain gauges as part of the installed system. Although accurate daily rainfall measurements are less important for furrow irrigation they will be of great value to those growers who wish to check rainfall volumes without visiting the farm.

An interesting set of devices manufactured by MAIT is the cable replacement system (MAIT, 2015). These devices are not part of the iNTELLiTROL system and hence can theoretically be used with any automation system. The cable replacement transmitter (CR-T) and cable replacement receiver (CR-R) enable transfer of a signal (e.g. 4-20 mA or 0-5 V) from one location to another location. Each of these units has a cost of $850. Other components available in this range include the Bi-Direction Switch (CR-X) which is designed to send on-off signals and the Repeater (CR-V) which can be used to extend the radio range.

5.7. Preliminary costs and Justification of Investment

5.7.1. Hypothetical Farm Design

As there is no one typical farm layout, a hypothetical farm layout (Figure 5-31) will be used to illustrate the components of the system and later the potential costs of the system. The farm is comprised of nine (9) irrigation sets of various sizes, the furrow lengths and number of drills (assuming 1.5 m centres) are given in Table 5-17. The sizes of the blocks vary from 1.52 ha up to 5.49 ha with an average of 3.85 ha which sits midway between the Linton and Pozzebon properties, which were two farmer collaborators in this project.

Water is supplied by two pumps, both pumps have a flowrate of 40 L/s and deliver water into the same underground mains pipe. This pipe can supply water to any field in the farm, theoretically any set can be irrigated with either or both pumps. The total pumping capacity is 80 L/s or 288 m^3/hr.

Table 5-17 –Characteristics of the hypothetical farm

Block	Length (m)	Drills (No.)	Area (Ha)
1	400	25	1.52
2	400	60	3.04
3	400	60	3.65
4	400	60	3.65
5	600	30	2.74
6	600	50	4.56
7	600	50	4.56
8	600	50	5.49
9	600	50	5.49
		Total	34.69

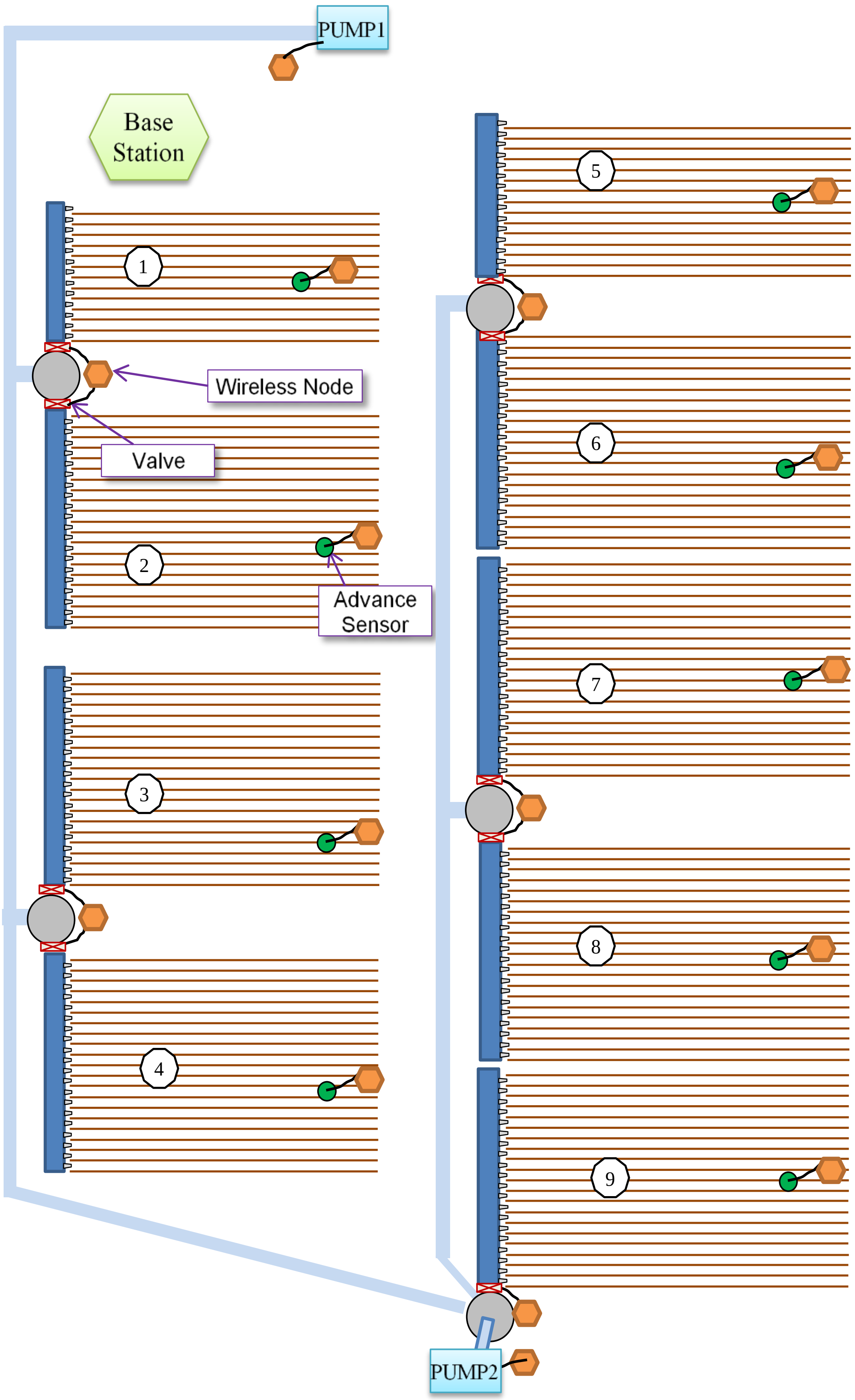


Figure 5-31 – Schematic of the field layout of the hypothetical farm

5.7.2. Preliminary System Costs

In 2015, before proceeding with the selection of sites and purchase of equipment a preliminary cost analysis was performed based on available technology and the hypothetical farm design given above. The system costs will be based on the automation of the hypothetical example farm as introduced above (Figure 5-31) with nine blocks and 2 pumps and a total area of 34.69 ha. Each block will require a single valve and actuator. For blocks 1-8 there are two valves positioned at the same riser which for some suppliers reduces the system cost due to the ability to control multiple actuators from a single radio node. It is also assumed that the pumps require a dedicated radio node where in reality they may be situated close to one of the valves thereby offering the potential of connecting both units to a single radio node.

Three different suppliers (Rubicon, WiSA and Observant) were considered, each with two potential scenarios. Padman was not considered in this analysis because their current product range is too far removed from Burdekin furrow irrigation systems. The prices and costs of MAIT are similar to WiSA and therefore there was no need to consider both options in the following simple analysis.

All costs below are ex GST and do not include install costs, retail mark-up, product support or electrician costs for connection of pump.

Scenario 1: Rubicon with Linear actuators

Each Rubicon node is capable of powering two actuators, therefore the system requires 5 control nodes. Each pump has a dedicated control unit node. The system also includes one base station. The advance detection involves one Floodtech probe in each block.

Control System Cost = 18,800 (control) + 4,600 (pumps) + 5,250 (base station) = $28,650
= $826 per ha
Data cost = $450 + 7 x $10 per year = $15/ha per year
Cost over 7 years = $931 per ha

Total system with advance detection = $28,650 + (Floodtech probes) $22,500 = $51,150
= $1,474 per ha
Data cost = $450 + 16 x $10 per year = $18/ha per year

Cost over 7 years = $1,600 per ha

As the Rubicon system is a cloud based system there is a data cost per year of $450 for the base station plus a nominal $10 per year for each radio device. When spread across the farm area this equates to $15/ha per year for the control system and $18/ha per year for the full system.

Scenario 2: Rubicon with Rotational Actuators

Each Rubicon node is capable of powering two actuators, therefore the system requires 5 control nodes. Each pump has a dedicated control unit node. The system also includes one base station. The advance detection involves one Floodtech probe in each block.

Control System Cost = 30,500 (control) + 4,600 (pumps) + 5,250 (base station) = $40,350
= $1,163 per ha + $15/ha per year
Cost over 7 years = $1,268 per ha

Total system with advance detection = $40,350 + (Floodtech probes) $22,500 = $62,850
= $1,812 per ha + $18/ha per year
Cost over 7 years = $1,968 per ha

As the Rubicon system is a cloud based system there is a data cost per year of $450 for the base station plus a nominal $10 per year for each radio device. When spread across the farm area this equates to $15/ha per year for the control system and $18/ha per year for the full system.

Scenario 3: WiSA linear actuator

One WiSA node can service 2 linear actuators, therefore the system will require 5 nodes plus one each for the pumps and one base station. The advance detection involves one soil moisture probe in each block connected to a WiSA node (each node can service two blocks)

Control System Cost = 16,225 (control) + 7,440 (pumps) + 2,945 (base station) = $26,610
= $767 per ha

Total system with advance detection = $26,610 + $17,125 (advance sensors) = $43,735
= $1,261 per ha

Scenario 4: WiSA rotational actuator[2]

One WiSA node can service 2 rotational actuators, therefore the system will require 5 nodes plus one each for the pumps and one base station. The advance detection involves one soil moisture probe in each block connected to a WiSA node (each node can service two blocks).

Control System Cost = 29,725 (control) + 7,440 (pumps) + 2,945 (base station) = $40,110
= $1,156 per ha

Total system with advance detection = $38,700 + $17,125 (advance sensors) = $57,235
= $1,650 per ha

[2] It is uncertain if the WiSA node has sufficient power to actuate two rotational actuators, the cost will climb to $1,920 per ha if each valve requires an individual node.

Scenario 5: Observant system with linear actuator and EnviroPro soil moisture.

This system represents a system assembled by the NCEA using Observant C3 nodes at every riser and LINAK linear actuators at every valve. As a result, this system will require a total of 5 nodes plus one for each pump. The advance detection consists of one Observant C3 Node in each block which will have capability for soil moisture and advance measurement. The soil moisture probe is an 80cm (8 sensor) capacitance probe.

Control System Cost = 17,528 (control) + 6,334 (pumps) = $23,592
= $680 per ha + $41/ha per year
Cost over 7 years = $967 per ha

Total system with advance detection = $23,592 + $18,000 (advance sensors) = $41,592
= $1,199 per ha + $59/ha per year
Cost over 7 years = $1,532 per ha

As the Observant system is a cloud based system there is a data cost per month for every actuator and sensor attached to the system. Based on the number of actuators and sensors it is estimated that the cost will be $41 per year for the base system and $59/ha per year for the complete system.

Scenario 6: Observant system with 1 actuator per node

Later in the project it was discovered that the Observant node would only be capable of controlling a single linear actuator. This increases the costs as follows:

Control System Cost = 25,938 (control) + 6,334 (pumps) = $32,272
= $1,116 per ha
Data cost = $41/ha per year
Cost over 7 years = $1,403 per ha

Total system with advance detection = $32,272 + $18,000 (advance sensors) = $50,272
= $1,449 per ha + $59/ha per year
Cost over 7 years = $1,862 per ha

As the Observant system is a cloud based system there is a data cost per month for every actuator and sensor attached to the system. Based on the number of actuators and sensors it is estimated that the cost will be $41 per year for the base system and $59/ha per year for the complete system.

5.7.3. Summary

A summary of the above six case studies is provided in Table 5-18 below. Here the data costs for the Rubicon and Observant systems have been calculated based on a 7 year equipment lifespan. The WiSA system does not include a data cost as the farmer is responsible for maintaining the base station and server computer. The costs of the base level control system range from $767 up to $1,403 per ha which is a significant difference. This difference declines when considering the full system with advance feedback where the prices range from $1,261/ha to $1,968/ha. The addition of probes to monitor advance rate increases the cost of the system by between $500 to $600 per hectare depending on the manufacturer.

Table 5-18 – Summary of price estimates for automation systems applied to the hypothetical farm

	Scenario	Control system			With Advance Feedback		
		Total	Per ha	Inc. 7 yrs data	Total	Per ha	Inc 7 yrs data
1	Rubicon linear	$27,775	$826	$931	$51,150	$1,474	$1,600
2	Rubicon rotational	$39,475	$1,190	$1,295	$62,850	$1,812	$1,968
3	WiSA linear	$26,610	$767	$767	$43,735	$1,261	$1,261
4	WiSA rotational	$38,700	$1,156	$1,156	$55,825	$1,650	$1,650
5	Observant linear[1]	$23,592	$680	$967	$41,592	$1,199	$1,532
6	Observant linear with one node per valve	$32,272	$1,116	$1,403	$50,272	$1,449	$1,862

[1] this option was found to be impossible after initial testing of the Observant nodes which could only power a single actuator

Scenario 5 appears to be very attractive but it was later found after sample nodes were purchased that the Observant C3 nodes are not capable of controlling two linear actuators from the one valve. It is interesting to note the impact of the data cost on the overall system cost. Scenarios 1, 3 and 6 have a similar up-front capital cost but once the data cost of the lifetime is added the Observant system increases by $413/ha and the Rubicon system by $126 per ha. As a result, the Observant system becomes the highest cost linear actuator system.

The main outcome from this analysis was that the cost differences between the suppliers considered was minimal and did not rule out any of the options to be considered for local testing. The project team then focussed on identifying those technologies which were easiest to adapt, better supported and more user friendly for the grower.

5.8. Potential Performance Improvements

At the start of the project a simple benchmarking exercise was carried out to estimate the potential irrigation performance increases which might be possible through precise automated furrow irrigation. This analysis was performed in two parts, firstly a broad benchmarking study based on bulk volumetric measurements and secondly a SISCO analysis based on evaluations of single measured events on a small number of fields.

5.8.1. Broad benchmarking study

This first set of data was collected by the Burdekin Productivity Services through the Rural Water Use Efficiency Irrigation Futures project. The information collected included field characteristics, flowrates, run times, and typical irrigation cycles. While this data does not allow for a detailed IrriMATE^{TM}/SISCO analysis it does permit rough estimation of water use efficiency and therefore an indication of the possible potential gains in efficiency. Data was collected from 20 different locations in the Burdekin, a summary of that data is as follows:

Number of locations = 20
Average field length = 712.5 m *(range 335 m to 1400 m)*
Average flow (per furrow) = 1.42 L/s *(range 0.35 L/s to 2.44 L/s)*
Average depth applied = 83.0 mm *(range 34.9 mm to 211 mm)*
Average depth required = 58.7 mm *(range 42 mm to 98 mm)*

The simplistic nature of the data does not allow calculation of the efficiency, but the following conclusions can be drawn:

- 7 out of the 20 fields had inadequate irrigations, i.e. the water was not able to replenish the water extraction. In this case there would be a water use increase but also yield increase if the irrigation management was improved.
- 13 of the 20 fields had excess irrigations with an estimated average efficiency of 64.5%. It should be possible to reduce water use at these sites with improved irrigation management.

Previous research conducted by the NCEA has indicated that in most cases the application efficiency of furrow irrigation can be improved to 85 – 90% level through use of an appropriate flow rate and stopping the irrigation at the correct time.

Assuming any irrigation with less than 80% efficiency could be lifted to 80% efficiency the average potential reduction in water use would be 19.7 mm over the entire 20 fields. This number assumed that the 7 fields with inadequate application have a 0 mm potential reduction

Assuming each field receives 20 irrigations per season these above numbers equate to:

Average requirement = 1173 mm
Average applied = 1601 mm
Average potential saving = 393 mm *(over all 20 fields)*

Therefore, based on these sites there is an average potential water saving of 393 mm or 3.93 ML/ha per season based on the assumption that application efficiency can be lifted to 80%. It is important to note that 7 out of the 20 fields clearly have a problem in that insufficient water is being applied which would be having a direct impact on yield.

5.8.2. Analysis of Field measurements

This section is an analysis of IrriMATE™ irrigation measurements that were collected in the Burdekin during a previous project by the NCEA (in 2008) and as part of this project. A total of 9 sites have been evaluated, with single events monitored at each site. The measurements conducted at each site included field characteristics, flowrates, water advance at several distances down the field and some estimation of the soil moisture deficit. The sites tested represent the range of soils common across the region from the clay soils, which are more common within the Burdekin Haughton Water Supply Scheme (BHWSS), to the lighter sandy loams on the lower delta and a silty loam with a low infiltration rate. Sites 8 and 9 represent two fields at the same site, one just after cultivation and one on a mature crop with a more representative deficit. The data from 8 and 9 were combined to form one data set for potential benefit. Table 5-19 contains a summary of the nine sites including the measured flows and times. Each one of these irrigations was managed by the farmer and therefore should be representative of a typical irrigation event for that field.

This data was entered into SISCO to determine soil intake rates and then SISCO was used to evaluate current performance and potential performance under altered inflow times and rates. The applied depth and application efficiency values represent the measured total application rate which includes all field losses (deep drainage and runoff) and the related application efficiency.

Table 5-19 – Summary of irrigation evaluations

	Location	Soil	Field length (m)	Flow (L/s)	Time (min)	Applied depth (mm)	Runoff recycled	Measured Application Effic. (%)	Maximum Potential saving [1] (ML/ha/yr)	Potential saving [2] at current flowrate (ML/ha/yr)
1	Southern lower delta	Clay loam	478	2.5	658	135.9	No	40.5	14.6	11.7
							Yes[3]	52.4	7.02	5.62
2	Southern lower delta	Sandy loam	373	0.958	1600	164.5	No	33.0	19.7	-6.13
							Yes[3]	33.1	9.46	-2.94
3	River bank	Loam	424.5	2.351	660	141.5	No	42.4	15.0	15.0
							Yes[3]	54.6	7.18	7.41
4	BHWSS	Clay loam	709	2.053	1080	123.4	No	48.6	6.31	1.83
							Yes[3]	53.0	3.03	0.88
5	BHWSS	Clay loam	714	2.06	630	71.7	No	82.8	1.63	0.68
							Yes[3]	89.6	0.78	0.33
6	BHWSS	Loam	832	1.29	1429	81.6	No	61.5	6.97	2.61
							Yes[3]	59.0	3.34	1.25
7	River bank upstream	Loam	473	1.672	645	90.0	No	57.5	4.98	0.14
							Yes[3]	62.0	2.39	0.07
8[3]	River bank upstream	Silty loam	412	1.263	2116	212.7	No	62.9	--	--
							Yes[3]	63.3	--	--
9	River bank upstream	Silty loam	392	0.544	715	32.51	No	61.4	--	--
							Yes[3]	86.4	--	--
8 & 9	Assuming 3 irrigations behave like 8 and 17 behave like 9						No	--	3.73	-2.12
							Yes[3]	--	1.79	-1.02

[1] Maximum potential reduction in water use assuming that both the flow and time can be altered and that there are 20 irrigations in a season.

[2] Maximum potential reduction in water use assuming that the flow remains as measured and the time can be altered and that there are 20 irrigations in a season.

[3] Efficiency and water saving assuming that 75% of runoff is recaptured and therefore not lost.

There were a number of scenarios modelled for each field, but two of these are presented in Table 5-19, the maximum potential saving and the potential saving under the current flowrate.

The **maximum potential saving** was found by optimising both the inflow rate and cut-off time in order to find the management strategy which will satisfy 95% of the soil moisture deficit across the entire length of the field and approx. 5% runoff to account for the normal variability that exists in the field and ensure that all furrows should be completed. This water use was then compared with the measured applied depth to generate a saving. The seasonal saving was found by multiplying this value by the assumed 20 irrigations in a typical season.

The **potential saving at current flowrate** follows a similar logic but this time the flowrate is maintained at the measured flow and only the time to cut-off is altered in order to optimise the performance. This column of potential saving is far more practically achievable than the maximum potential saving because it does not require any modification to pumping or pipeline infrastructure or set size, but simply that the irrigation is shut off at the correct time. Therefore, this potential saving at current flowrate is the best simple estimate of the possible performance with automation.

The **Runoff Recycled** provides a second set of efficiencies and potential savings if the grower already uses a tail water recycling system under the measured conditions. Some farms in the Burdekin have the ability to recycle tail water losses through the use of tail water storages and pumps. This means that runoff is not strictly a loss to the system. To account for this a second set of efficiency and potential savings are included which assumes that 75% of the tail water is recaptured and used in a subsequent irrigation.

The measured application efficiencies, assuming that all runoff is lost, varied from 32.9% up to 82.8% with an average of 50.1%. Interestingly these efficiencies are much lower than those captured from the broad benchmarking study. The application efficiencies assuming runoff is recycled varied from 33.1% to 89.6% with an average of 58.3%.

The maximum potential water saving across sites 1-7 and the 8&9 combination ranges from 1.63 ML/ha up to 19.7 ML/ha. The three sites with greater than 10 ML/ha potential water saving are on the extreme end with long irrigation times on highly permeable soils. Accounting for tail water recycling, these potential savings change to a range of 0.78 ML/ha to 9.46 ML/ha.

The potential savings under the current flowrate are more realistic of what could be achieved with automation. Here the potential savings range from negative values up to 15 ML/ha for no tail water recycling and 7.41ML/ha if tail water recycling is practiced. The negative values indicate that for those irrigations an optimised irrigation management would require a greater irrigation application than is currently used.

The average potential water saving under the current flowrate across sites 1-7 and the 8&9 combination amounts to 4.05 ML/ha without tail water recycling and 1.94 ML/ha with tail water recycling, assuming that negative savings are zero in this average.

5.8.3. Water Charges and Pumping Costs

5.8.3.1. Water Charges

Growers use a range of water sources depending on their location within the Burdekin region. Groundwater is used throughout the region with more intensive use on the lower Burdekin Delta. A small number of growers may access water directly from the river at a small SunWater charge. A majority of growers will have access to either a SunWater scheme channel or a Lower Burdekin Water

(LBW) channel or regulated creek. A large proportion of growers may have access to both regulated supply and groundwater. The usage charges vary depending on the source used. In the LBW management area, groundwater access is on a per ha basis with no extra usage charge. Many irrigators rely either solely, or in part, on one of the water schemes, Table 5-20 contains the water access charges for the three main schemes within the study area. In the 2014 - 2015 season the variable water access charges ranged from $13.97 to $26.03 per ML, in 2017-2018 the prices ranged from $15.49 to $28.70 for water within allocation. These costs are expected to increase naturally with inflation, however in some cases it has increased by 10% in the single year with the cited reason being the electricity price increases.

Table 5-20 – Water access charges (ink GST) for the Northern Division of the LBW (NLBW), Southern Division of the LBW (SLBW) and SunWater

	Item	2013-2014	2014-2015	2017-2018	Comment
NLBW	Area Charge	$135.00 p ha	$139.05 p ha	$149.00 p ha	Growers 2/3 Wilmar 1/3
	Channel Base Rate	$20.43 p ML	$20.43 p ML	$21.35 p ML	For first 8 ML
	Channel Excess Rate	$35.79 p ML	$35.79 p ML	$37.57 p ML	For excess
SLBW	Area Charge	$119.05 p ha	$130.97 p ha	$145.20 p ha	Growers 2/3 Wilmar 1/3
	Channel Base Rate	$13.97 p ML	$15.37 p ML	$17.04 p ML	For first 8 ML
	Channel Excess Rate	$28.99 p ML	$31.88 p ML	$33.25 p ML	For excess
SunWater	Allocation Charge	$27.27 p ML	$30.05 p ML	$38.41 p ML	Fixed Cost
	Water Charge	$26.03 p ML	$26.65 p ML	$28.70 p ML	Variable cost
	Estimated cost for water over allocation	$53.30 p ML	$56.70 p ML	$67.11 p ML	For excess over allocation

Most of the farmers that access this scheme water need to pump the water in order to deliver the water at the required head for the field. There are a number of instances where no pumping is required. The pumping costs involved will be of similar magnitude but lower than the bore pumping costs due to reduced head.

Across the three regions considered, the average water price is currently $23.03 per ML for the first 8 ML (or allocation) rising to between $33.25 and $67.11 per ML for further water use.

5.8.3.2. Pumping Costs

Most fields in the Burdekin require some form of pumping, which in most cases involves an electricity cost. Use of automation systems will in many cases have a significant impact on the total volume of water used and hence have a direct impact on these energy costs. Current work by the Burdekin Bowen Integrated Floodplain Management Advisory Committee Inc (BBIFMAC) through the Energy Efficiency Gains for Australian Irrigators (EEGAI) project has involved the evaluation of pump performance across a large number of properties. The collated data includes pump model, size and type, electric motor size, flowrates, inlet and outlet pressures, suction water levels, power consumption and energy tariffs. From the database, a total of 37 evaluations were conducted within the Burdekin, which have been used in this report in an attempt to quantity typical pumping costs. The data collected allows separation of the results into the Burdekin-Haughton scheme region and the Lower Burdekin regions. The data as further sub-classified by water source due to the expectation that pumping from ground-water should involve greater energy costs than pumping from a scheme channel or creek. Summary results are given in Table 5-21

Although the database does contain information on the specific electricity tariff used by each pump, it does not include the times of day that each pump is used and therefore estimation of actual prices is difficult because of the large proportion of farmers using one of the time of use tariffs. For this reason, all costs within Table 5-21 are based on the price of $0.25 per kWhr. The first pumping cost column refers to the average, and the second to the range of values. For example, Lower Burdekin groundwater includes 18 well and bore pumps across the lower Burdekin area.

Table 5-21 – Summary of pumping costs (from IPERT)

Area	**Source**	**No. tested**	**Flows** (L/s)	**Pumping cost*** ($/ML)	
Burdekin-Haughton	Channel	3	75 - 305	$15.79	4.81 – 34.17**
	Groundwater	3	44 - 66	$21.14	19.01 – 23.23
	River	2	62 - 112	$21.49	21.24 – 21.73
Lower Burdekin	Channel	2	73 - 93	$13.59	11.87 – 15.31
	Creek	1	59	$23.09	23.09
	Lagoon	3	45 - 75	$13.42	12.58 – 14.97
	Recycling Pit	2	50 - 51	$12.22	9.61 – 14.82
	Groundwater	18	23 - 72	$21.18	13.57 – 36.91
	River	3	21-102	$32.51	18.20 – 57.86

***assuming $0.25 per kWh**

**** The $34.17 value is due to poor pump efficiency**

The analysis conducted across the small number of farms tested indicates that the pumping costs range from $4.81 per ML up to $57.86 per ML with the majority being in the $15 to $25 per ML range. These figures are generally lower than for most other regions due to the low pressure requirements of the fluming, and the shallow water-tables and high creek and river levels. However, the volumes pumped per ha are generally much higher in the Burdekin than other irrigation areas with seasonal water use commonly ranging from 10 – 30 ML per ha. As expected, the cost of groundwater pumping is higher than from the channel. Pumping from the river involves similar or slightly larger costs than ground water, due to the fact that in most cases the river lift exceeds that of the bores or wells. It is important to note that the only costs in Table 5-21 are the electricity usage or variable charges, it does not include any fixed daily charges or peak power based charges.

The following pumping energy prices have been assumed for further analysis based on the data summarised in Table 5-21.

- C – channel no pumping $0.00/ML
- CP – channel with pumping $15.00/ML
- G – groundwater $21.00/ML
- R – river $25.00/ML
- D – recycled from drainage $12.00/ML

A value of $15 per ML is assumed for channel pumping, $21 per ML for groundwater pumping and $25 per ML for river pumping but these values are merely based on the averages and individual pumps may have values within more than +/- 50% of this figure. Assuming a seasonal pumping volume of 20 ML/ha these indicative prices result in a cost of $300 and $420 per ha for groundwater and channel respectively

Many of the farmers using groundwater, and therefore with higher pumping costs due to increased lift, are also those farmers who tend to over-irrigate because many of the groundwater areas have soils with high permeability. For example, one of the pumps in the lower Burdekin supplies an estimated 23.4 ML/ha at a cost of $24.10 per ML resulting in a seasonal pumping cost of $564 per ha.

One of the key objectives behind these pumping measurements was to ascertain potential gains in pumping efficiency. Although some pumps may be operating at a sub-optimal level the most significant energy savings across the industry will be a reduction in total volumes pumped.

5.8.4. Conclusion

The findings of the broad benchmarking study indicate a potential water saving of 3.93 ML/ha while the more comprehensive analysis of a smaller number of fields indicate an average potential water saving of 4.05 ML/ha by better control of irrigation run times. More importantly, these potential savings vary widely between sites and therefore it is difficult to generalise what the potential savings might be on an industry wide level.

Water usage costs range between $0 per ML for groundwater, $17.04 to $28.70 for water within allocation and $33.25 to $67.11 outside allocation. Pumping costs also vary between sites but for the Burdekin with low operating pressures average around $15/ML for channel water and $21/ML for ground water. The combined water and pumping costs range from $21 per ML for groundwater up to $82.11/ML for pumped SunWater outside allocation.

Combining these different variables leads to the conclusion that better management of the irrigation run times would lead to water savings averaging close to 4 ML/ha with a combined water and pumping cost between $84 to $328 per ha. These figures are based on many assumptions and represent average savings and costs. Quantifications of actual costs for the three sites are given in sections 6-3 to 6.5.

5.9. Reliability and Durability

Success of the automation system hinges on its ability to withstand expected environmental conditions and remain functional during minor failures of its components.

A key feature needed by farmers is the inclusion of manual overrides in the event of system failure. One clear example is where the system fails to open or close a valve at the designated time. Firstly, the system should notify the user of this failure so remedial actions can be taken. The system should allow the user to access the valve controls remotely, ideally to check the current status of the valve, and then to manually repeat the desired valve open or closure. If this does not work or the valve does not respond the valve control mechanism should allow the irrigator to easily open or close that valve manually in person.

When installed in the field it is expected that various components may be exposed to sunlight, dust, rain and irrigation water all of which have adverse impacts on electrical components. The IP rating or International Protection Marking is one way to assess the ability of components to withstand both solid particles such as dust and soil and also water from rain or during irrigation. When rated, components will be assigned a two-digit code, IPXX, where the first digit represents the resistance to solid objects, i.e. dust and the second digit to liquids, i.e. water. The required level of protection varies between the location of each component, but it is expected that components not in contact with the ground will have minimum protection of IP54 while components that are expected to be in contact with soil or the irrigation water should have IP67 or better (Table 5-22).

Table 5-22 – IP Ratings that are relevant for components of the automation system

IP CODE	Definition	Comments
IP5X	Ingress of dust is not fully prevented but dust will cause no harm	May be acceptable for components that are not in contact with ground.
IP6X	No ingress of dust, dust proof	Will be necessary for any components at ground level
IPX4	Protected against splashing from any direction	A minimum requirement for any components that may be exposed to rain
IPX5	Protected against low pressure water jets from any direction, some water ingress permitted	
IPX6	Protected against high pressure water jets from any direction, some water ingress permitted	
IPX7	Protected against short periods of submersion in water	Required for components at ground level in field
IPX8	Protected against long periods of submersion in water	Desired for components at ground level in field

The reliability and durability of components was a key consideration in the selection of all components used in the demonstration trials. A good example is the automation radio nodes. One criticism from some observers to the project is that the electronic components used in these systems are relatively simple and made up of components which could be potentially purchased for a fraction of the manufacturers' cost. While this might be true in some respects, the systems described above (e.g. WiSA, MAIT, Rubicon) have been built to withstand outdoor conditions exposed to extremes in ambient temperatures, rainfall and high humidity. These systems have also been refined over a number of years as the designers learnt from previous design flaws. Furthermore, these providers will support the equipment under a warranty when they are installed in these extreme outdoor conditions.

This same principle applies to the control software associated with these components. The software has been tested in other industries over a number of years and therefore purchasing one of these systems should ensure that the system will have minimal software problems.

5.10. Conclusions

This chapter has outlined the range of valves, actuators and automation systems which were available at the time at which this project started the instrumentation of the three project demonstration sites.

A review of available valves determined that existing butterfly valves while being simple were also cost effective and could be potentially retrofitted with powered actuation. Electric linear actuators were preferred to pneumatics or electric rotational actuators because of cost and the ability for a simple solar power supply to provide enough power to open and close the valves.

A range of different automation systems are currently available and used in the dairy industry for border check irrigation, and the price does not vary significantly between the different suppliers. WiSA was chosen as a preferred option because of the known capability of the system to control at least two actuators from a single radio node, which would almost halve the cost of the control system.

The report has presented a brief summary of a benchmarking study which was conducted early in the project to gain a picture of the potential water and energy savings if automation led to improved irrigation management. It was difficult to make any conclusions due to the highly variable nature of the current level of irrigation performance, with some growers applying insufficient water and others applying up to double the seasonal requirement. Part of this variability may have been caused by the fact that this study was based on single events at each site.

The findings of this scoping study were presented to the project steering committee in mid-2015 who concluded that there was merit in proceeding with the trial and that sites should be selected to show the merits of the system in different soils and water sources. It was also decided that these sites should be geographically spread across the district so that growers would find it easier to relate to their own farm situation.

6. DESCRIPTION OF SITES

6.1. Introduction

This section will describe the demonstration sites, the design of the system at each site and the installation of equipment at each site. The three sites within this project are the Pozzebon, Linton and Jordan properties.

Table 6-1 Summary of Automation Sites

Site	Owner	Description
A	Denis Pozzebon	Multiple pumps from channel in Lower Burdekin Water area supplemented by bores and recycle pits. Automation of 8 blocks.
B	Aaron Linton	Two pumps from Burdekin River supplying 11 furrow irrigated blocks. Farm already had 45 ha of sub surface drip installed prior to the project. Once installed the entire farm irrigation system will be automated.
C	Russell Jordan	Gravity supply from channel in Burdekin-Haughton scheme. Automation of 5 blocks out of 7 within that farm.

6.2. General System Design

This section will outline the general system architecture that is common to the three sites and would be common to any site using WiSA automation hardware. The equipment deployed on each site will be described under subheadings for those sites and the specifications of most components are given in Chapter 7.

6.2.1. Base Station

The base station is the collection of hardware which communicates to the field units and controls the flow of data and irrigation control commands. In the case of WiSA the base station consists of a radio antenna and base station module which is connected via USB to a personal computer. This computer runs the computer software packages described in section 7.3 and remains turned on 24hrs per day. The antenna is installed at a high point, such as the top of a roof, and the computer and base station module is located in a convenient location in the farm or home. Ideally, this computer should remain dedicated solely for use with the automation system, but in both the Jordan and Pozzebon cases they use the base station computer for other business or personal tasks.

In cases where the farm is located too far from the house, the base station can be installed in a shed such as is the case for the Linton farm. In this case, the base station module, computer, backup power supply and mobile internet dongle is housed within a plastic container to protect the hardware from dust and insects as shown in Figure 6-1.

Figure 6-1 – Base station at Linton site

A single base station is capable of communicating to hundreds of field units so it is unlikely that growers will need any more than one unit unless the farms are located more than 5km apart.

6.2.2. Control of field inflow

The review of equipment document completed in 2015 (summarised in Chapter 5) outlines the range of valves and actuation techniques which might be applicable for low pressure pipeline systems such as is common in the Burdekin. From this review, it was concluded that the most practical and cost effective way to automate the water supply was through electrically actuated butterfly valves. Both rotational and linear actuators can be used but it is the linear actuators which are far less expensive and easier to integrate with 12 V solar powered nodes such as the WiSA nodes. Use of a linear actuator will require a lever to convert the linear force to a rotational torque to turn the valve.

The linear actuator selected based on price, actuator force and durability (section 5.4.1) is the LINAK LA35 which is available in a range of stroke lengths. The version chosen for this project is the 300mm stroke length which is rated to 6000 N push and 4000 N pull. The LA35 300mm has a length between mounting pins of 550 mm when retracted and 850 mm when fully extended. Although it is possible to purchase versions of the LA35 with position control it is far easier to design the lever attachment such that the actuator is fully extended when the valve is open and fully retracted with the valve is shut. This will eliminate the risk of the actuator over-rotating the valve stem past the nominal closed or open positions which may otherwise cause damage to the valves. While it is possible to orientate the actuator to be extended when the valve is shut it is preferred to have the actuator closed at this point so that the bare metal of the piston is not left exposed for long periods of time. Finally, the lever should be designed to maximise the mechanical advantage when the valve is in a closed position as this is where the valve requires the maximum torque. Once the valve clears the valve seat the torque required to turn the valve stem quickly diminishes. As a general rule, the linear actuator will have the greatest mechanical advantage when the angle between the actuator and the rotating lever attached to the valve is closest to 90 degrees.

At two out of the three sites detailed below the grower built their own lever arm attachment to suit each valve, saving an estimated $400 per valve. In these cases, the growers removed the existing valve lever stem and welded the required lever arms to the valve and the valve flange. The varying orientations of the valves and the shape of the cylinder near the valve meant that each lever has to be custom made and adjusted on site. It was proposed that a single design could be created that would suit any common valve size and orientation and could be quickly fitted to the valve on site. With assistance from the project team the local metal fabricator, COAR Engineering, designed a prototype (Figure 6-2) which would fit the majority of valves.

Figure 6-2 - Valve actuator lever prototype

This prototype was made up of four standard parts which would be welded to the valve stem and bolted to the valve flange on site. The $400 price used in the cost benefit analysis represents the fitted price of this lever arm attachment. In the event that the farmer wants to manually operate the valve, they can simply remove a small bolt from one end of the actuator and control the valve using the lever arm.

One concern evident in the previous discussion of butterfly valves is the significant torque that may be required to operate these valves. From Table 5-4 the recommended design torque for 300mm (12”) butterfly valves ranges from 226 Nm to 624 Nm. These figures would represent the maximum expected torque for these valves operating under significant pipeline pressure and would also include a factor of safety such that the actuation mechanism does not become jammed. Nevertheless, these numbers do give some idea of the potential torque requirement. A schematic of the lever prototype shown in Figure 6-2 is given below in Figure 6-3 along with the lever arm lengths.

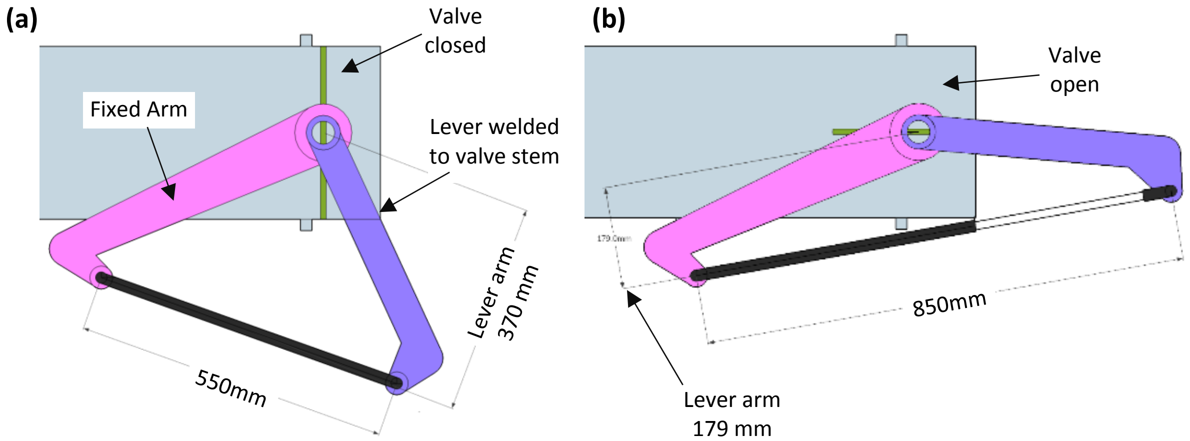


Figure 6-3 – Actuator lever prototype dimensions and lever arm lengths when (a) closed and (b) open

Some simple calculations can be completed to check the maximum torque that will be applied to the valve assuming that the levers are orientated according to Figure 6-2 and Figure 6-3.

At **closed** position: Pull force of 4,000N at a 370mm lever arm = 1,480 Nm (2,220 Nm push)
At **open** position: Pull force of 4,000N at a 179mm lever arm = 719 Nm (1,074 Nm push)

The torque generated by the LINAK LA35 and the prototype lever at closed position, where the valve requirement is likely be highest, far exceeds the maximum design torque for the butterfly valves. Even the seemly obtuse lever angle in Figure 6-3 (b) when the valve is opened is still potentially able to generate 719 Nm of torque, which is higher than is required by any of the butterfly valves found in the review. This level of safety does not extend to all potential linear actuators, for example the SKF CAHB-20 12V (Table 5-7) generates a maximum of 500 N which only yields 185 Nm which is lower than recommended actuator torque for any butterfly valve.

These simple calculations have shown that the LA35 actuator should be capable of operating any standard butterfly valve up to 300mm diameter.

Another important consideration is that the valves should be closed slowly to minimise the water surge or water hammer. According to the LINAK specifications the LA35 moves at a speed of 4.7mm/s

(1.6 A at 12V) under no load and 3.3 mm/s (7.5 A at 12V) under full load. This 4.7 mm/s speed equates to a maximum opening time of 64 seconds, which is slower than any manual closure.

6.2.3. Infield Application

In the Burdekin, sugarcane is typically planted in single rows on 1.52 m centres with an irrigation furrow between each row. The water is delivered to the furrows using flexible walled gated pipe (Figure 6-4.a) with one small plastic outlet per furrow. The flowrate delivered to each furrow is a function of the cup/outlet size and the pressure head in the line. This system of infield delivery is identical to what was in place at the site before the installation of the automated valves.

No modifications were made to the fluming or the fluming outlets at any of the three sites apart from ensuring that the fluming was set up so that minimal or no changes would be required to the system throughout the season.

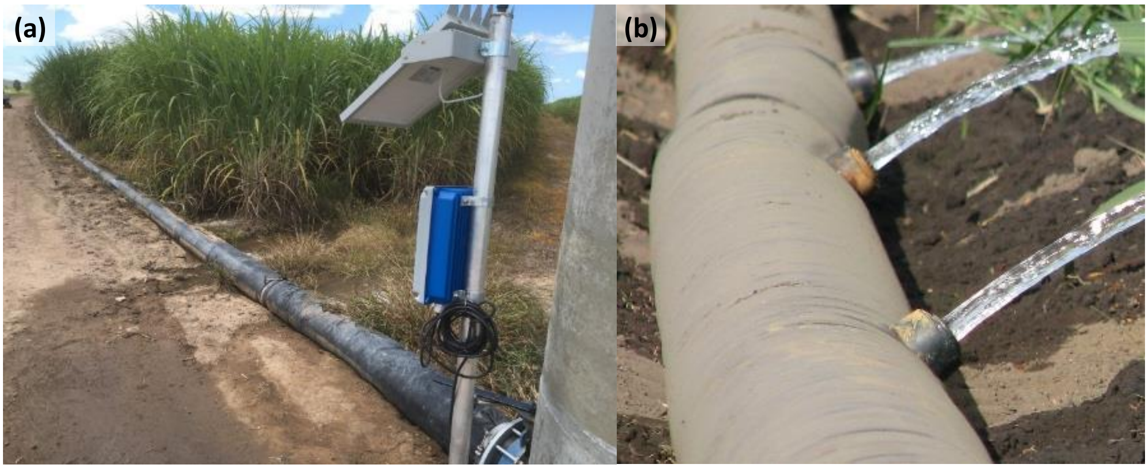


Figure 6-4 – (a) Fluming attached to valve and (b) example of outlets on gated pipe

6.2.4. Drainage and Advance Sensors

End of row sensors provide that simple but important check that water has reached the end of the field. They are even more crucial where the grower wants to regulate or minimise runoff losses from the field. The sensors used vary between the sites and will be discussed in detail under the appropriate headings below.

6.3. Pozzebon Site

6.3.1. Site setup

The farm owned by Denis Pozzebon is located 12 km south-west of Ayr on the northern side of the Burdekin River. The primary source of water is a nearby creek which is regulated by Northern Lower Burdekin Water (NLBW). Water is pumped into this creek from the Burdekin River further upstream. The farm also contains a number of bore pumps which were being used in the 2015-2016 season with the cuts in allocations.

Three sections of the farm were considered in the design phase with the final selection being a series of 6 irrigation blocks located on the southern end of Figure 6-5. This was later expanded to a total of 8 blocks in early 2017 by Denis.

Figure 6-5 – Satellite image of the Pozzebon Farm

These 8 blocks with a total area of 27 ha are irrigated through 5 risers (Figure 6-6). The water flow to each block is regulated through a valve and linear actuator connected to a WiSA node at the riser. The automated section represents approximately one third of the farm irrigated by the common underground mains system at this site. The costs and benefits in this document are derived based on the area currently under automation.

In terms of control, the entire farm is interconnected with the potential to irrigate any block with any combination of the channel and bore pumps. However, Denis usually irrigates the automated blocks only using the supply from the two pumps connected to the WiSA control. This interconnectivity of the system also means that additional fields could be added at a reduced cost compared to the current cost per unit area.

Figure 6-6 – Satellite image of the Pozzebon site

The Pozzebon site is set up with a tail water recovery system which pumps the water into the common water supply. Denis may automate these pumps sometime in the future when other parts of the farm are converted to automation. Blocks 1 and 2 drain toward the south (left in Figure 6-6) to a drainage pit on the side of block 1. Blocks 3 – 8 drain either straight across the headland or through culverts into a drain on the lower edge of the field which travels towards the north (right in Figure 6-6).

The irrigated area associated with each valve is given in Table 6-2.

Table 6-2 – Irrigation blocks within Pozzebon site

Block	Max. Length (m)	Spacing (m)	Width (m)	Drills (No.)	Area (ha)
Furrow 1	300	1.524	119	78	3.62
Furrow 2	300	1.524	101	66	3.06
Furrow 3	300	1.524	97	63	2.91
Furrow 4	300	1.524	83	54	2.53
Furrow 5	300	1.524	81	53	2.48
Furrow 6	300	1.524	84	55	2.55
Furrow 7	300	1.524	160	105	4.86
Furrow 8	466	1.524	139	91	4.89
		Area of Automation			26.9

The automation valves were installed on the first six blocks on the 24/03/2016 and have been used to control all irrigations since this date. The valves on sets 7 and 8 were installed in February 2017. The pressure sensor in the supply was installed on the 26/04/2016 and has recorded water level continuously since this date. The drainage probes were installed at a later date. Denis has plans to expand the automation to other parts of the farm in the near future.

Early in 2016 when the system was installed, there was some problems with the foot valves on the pumps meaning that the automation system could not start the pumps without checking for pump prime. This has since been fixed and now the pumps can be both started and stopped remotely using the WiSA system.

A summary of the main components of the system as of 1 July 2017 is as follows:

Major Components

- 5 x WiSA control nodes
- 8 x linear actuators and levers (Figure 6-7)
- 1 x submersible pressure sensor
- 5 x WiSA advance/drainage monitoring nodes
- 6 x Drain probes connected to WiSA nodes

Pre-existing equipment

- 1 x WiSA Pump control node connected to two pumps
- Base Station within Pozzebon home office

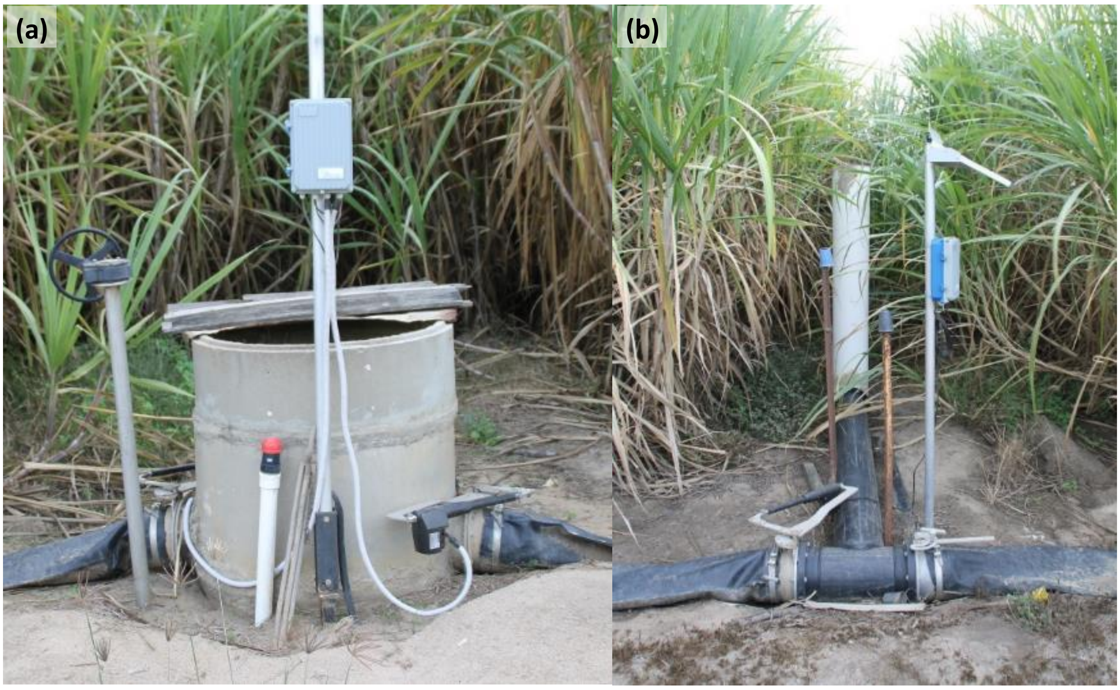


Figure 6-7 – Automation installed at valves for (a) blocks 1 and 2 and (b) block 6 at the Pozzebon site

6.3.2. Pozzebon System costs

The following costs are based on installing the current system across the 8 irrigation blocks without any prior infrastructure. In reality, Denis already had the pumps connected to the system, already had a WiSA base station and used an existing computer for control. The costs in this table reflect the commercial rate of installing this system in this field and include the component cost, the commercial mark-up, delivery to site, installation and support. The breakdown of the system as currently installed is as follows:

Table 6-3 Cost breakdown of system currently installed at Pozzebon site

Base Station	(costs are once off for farm)	Price	Qty	Total (inc GST)
Base station	complete with radio and aerial	3,000	1	3,000
Setup	software, bitmaps, dongle	1,500	1	1,500
Setup	licence ports	80	20	1,600
Computer		1,200	1	1,200
External HDD + UPS	backup	300	1	300
Internet		100	1	100
				$7,700
Pump Site	(control of both main pumps)			
Pump controller	24 output	3,000	1	3,000
Installation	electrician	500	1	500
Pressure transducer	4m submersible	800	1	800
Water meter	Already present but not connected	--	2	--
Flow Switch	Already present for manual system	--	2	--
				$4,300
Block Control				
Actuator control node	controls 2 actuators	3,000	5	15,000
LINAK Actuator	LINAK LA-35	500	8	3,000
Bracket	Green's valve	300	8	2,400
Bracket fitting	labour - COAR	100	8	800
				$22,200
End of Row Sensors				
Advance node	Can connect to any number of probes	3,000	5	15,000
Drainage Probes	SM probes	500	6	3,000
Install	Correct positioning, configuration	500	5	2,500
				$20,500
Commissioning	physical installation of the base station, field radios, and checking			**$5,000**
		Per ha		
Total (Entire system)		$2,211		**$59,700**
Without base station (i.e. another farm in radio coverage)		$1,926		**$52,000**
Entire system without drainage sensors (control only)		$1,452		**$39,200**
System installed during project		$1,767		**$47,700**

The "base station" includes all the equipment associated with the WiSA base station at the home office, including the computer and the software to communicate to the field nodes. With the exception of the licence ports, this is generally a once off investment as this same base station can communicate to a large number of radio nodes. The "pump site" costs include the installation of a radio control board to control and monitor the two main pumps in this system. Water meters are already present at this site and could be wired to the system in the future if desired. The "block control" encompasses the hardware at the top end of the field used to deliver the water to the 8 irrigation blocks. The "end of row sensors" are the optional system which is used to monitor the completion of the irrigation event. In this case five WiSA nodes were required to monitor the runoff without altering the drainage system. Finally, the commissioning cost of $5,000 is an estimate of the extra cost associated with the installation of the system and configuration of the base station.

6.3.3. Measurements in the supply

This section will describe those devices used to monitor and/or measure the water supply system at the Pozzebon site.

6.3.3.1. Pressure Head

In pumped systems such as this, the pressure head is the easiest characteristic to monitor and provides direct information on the operation of the valves. The system will normally operate at a constant pressure head for each valve which will be maintained for subsequent irrigations unless the number and/or size of cups is varies significantly. Pressure also provides a good means to detect failures in the system, and can be used to trigger a text message to the operator or automatic shutdown of the system.

In most of these irrigation systems, open cylinders (e.g. in Figure 6-8) are used to protect the pipeline from surges and to limit the pressures so that the fluming will not rupture. The water level in these cylinders is equal to the pipeline pressure at this point in the system which is directly related to the pressure at all points in the connected pipeline system. The water level in this cylinder varies over the range of 0 - 1.5 metres, therefore measurement of the pressure requires a sensor with a high accuracy over this small range.

Figure 6-8 – Pressure transducer installed at Pozzebon site.

A submersible pressure transducer (range of 0.2 bar or 2 metres) was installed within the riser for set 5 as shown in Figure 6-8. The PST is housed within a protective PVC pipe fixed to the inside of the concrete cylinder and set a level approximately equal to ground level such that the values reported are given as depth of water above ground. The PST measures a differential pressure between the pressure at the location of the probe and atmosphere (through a vented tube). This pressure value is converted to an equivalent depth of water within the WiSA software.

The PST provides a measure of the water head during irrigation of all blocks connected to that underground system, of which the automated section is approximately 1/3 of the total area. The impact of this can be seen in Figure 6-9 below where the red line is the depth of water in the cylinder above ground level. The line bottoms out when the pumps are off, rises above zero when the pumps are running and changes every time a valve is opened or closed somewhere in the farm. The coloured bars represent the 6 blocks that have been automated, the water height is different for each due to the changes in hydraulics between each set. The pressure sensor also reports values during times when none of the 6 automated valves are open as this is one shared underground mains system. Although this may be a slight inconvenience for the project, it means that the installed sensor gives the farmer a check on operation of all of the valves across the entire farm, regardless of whether that valve is automated or not.

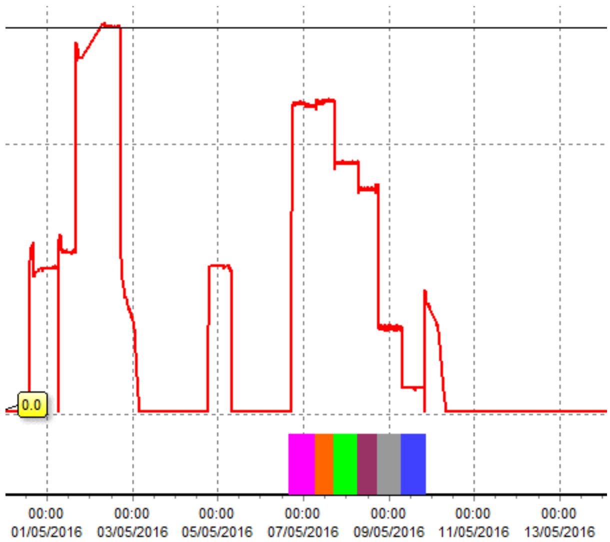


Figure 6-9 – Screenshot of pressure and valve open times at Pozzebon site

The data can be easily exported from the WiSA software and analysed as shown in Figure 6-10. In this example, each block was irrigated sequentially in chronological order 1-6, and the pressure head experiences an immediate change when the valves are opened and closed. A plot of pressure also gives a better indication of irrigation start and stop times than valve opening times alone, for example, in Figure 6-10, valve 1 is opened more than one hour before the pumps start and the irrigation commences.

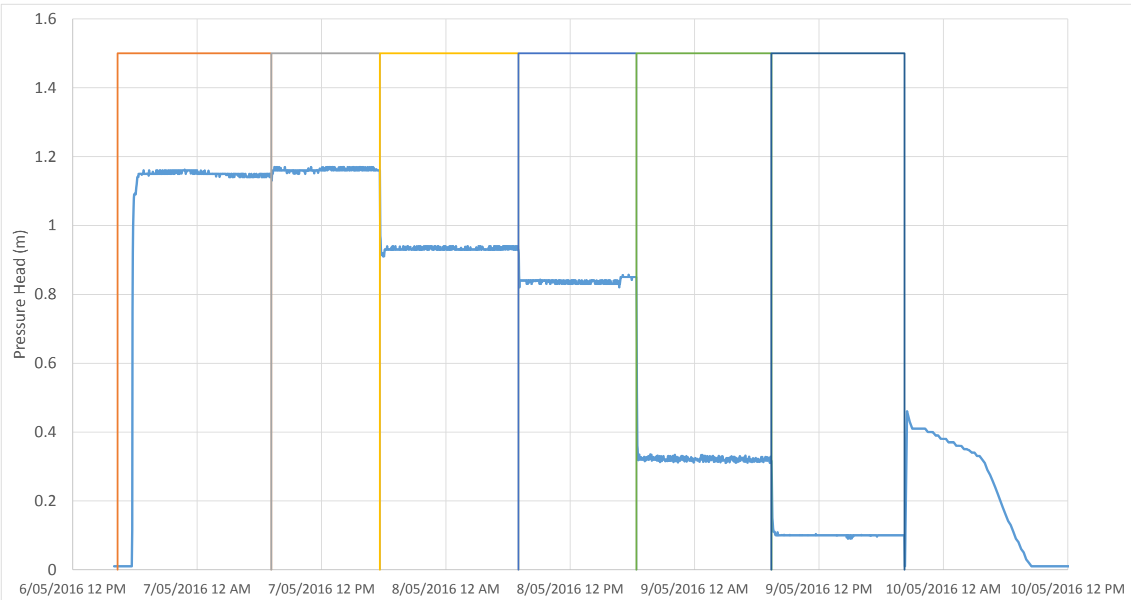


Figure 6-10 – Plot of pressure head during irrigations of the 6 automated blocks at the Pozzebon site.

In this case, the operating head is similar, but not identical, between blocks on the same riser, 1 and 2, 3 and 4 (Figure 6-10). This is explained by the fact that both blocks on the same riser contain a similar number of cups (and therefore flow) and source water from the same riser and therefore should have the same underground head loss.

6.3.3.2. Flowrate

The supply system at the Pozzebon site is complex, with two main pumps from a regulated creek (NLBW), a number of groundwater bores which are occasionally used during peak periods or when the creek water is limited, and two tail water recycling pumps. The two main pumps are already connected to NLBW scheme flowmeters for metering purposes and it should be theoretically possible to connect these meters to the nearby pump control. However, Denis has not desired for this to occur at this stage and has not asked for permission from NLBW. While connecting these meters to the system would provide useful data, it would be difficult to attribute the flow from these pumps to individual blocks because of the fact that they are connected to the same common underground pipeline mains as the groundwater and recycle pit pumps. It is likely that Denis may push to have these meters connected at a later stage when he moves to instrument other pumps on the farm with automation. The lack of flow information means that the project cannot estimate seasonal crop water use so the estimates of potential water savings presented in section 10.3 are based on the nominal flow of the larger of the two pumps.

6.3.3.3. Sample Observations from Supply

Figure 6-11 contains a plot of the water level in the cylinder from the PST described above between the start of April 2016 and the end of January 2017. It can be assumed that any time the head is above zero that there is an irrigation occurring in one of the automated blocks or one of the fields connected to the common underground supply pipeline. The maximum possible head in the cylinder is approximately 1.5 metres, any higher and the water will spill over the top of the cylinder. In this figure, there appears to be a small number of times where the water level reaches this maximum level.

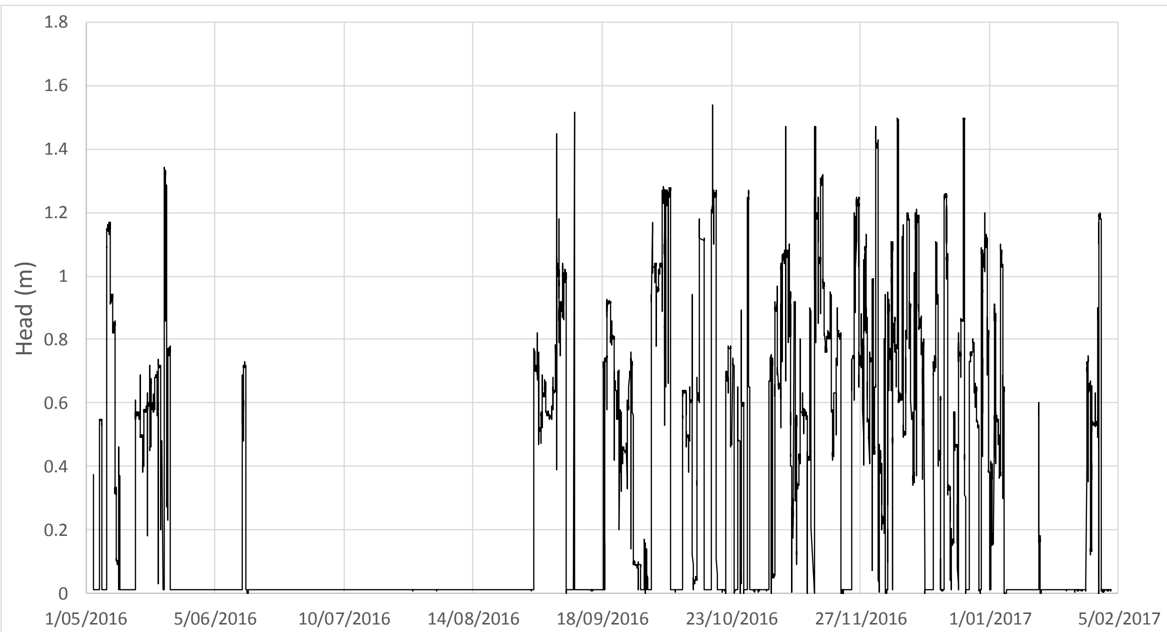


Figure 6-11 – PST head data at Pozzebon site since installation to Feb. 2017.

One of these occasions, where the water level reached the top of the cylinder, was the result of a failure in the irrigation system. On the 24th of December, while the system was irrigating block 3, the valve was shut prematurely while the pump was still running. Immediately the water level in the cylinder housing the PST rose from 0.75m up to 1.5m. As a result, it can be assumed that water was spilling out over the top of this cylinder until the next valve was opened by the system. At this time Denis was setting up pump run times and valve open and close times separately rather than allowing the WiSA scheduling system to start the pump according to the valve shift times.

While this cylinder overtopping did not cause any damage to the infrastructure, if left unchecked it may cause erosion around the cylinder or waterlogging to a section of the field. This fault could be prevented in the future by adding an alarm to the water level detected by the cylinder. Once a level (e.g. 1.45 m) is detected it could be configured to send an SMS to the farmer and/or switch the pump(s) off.

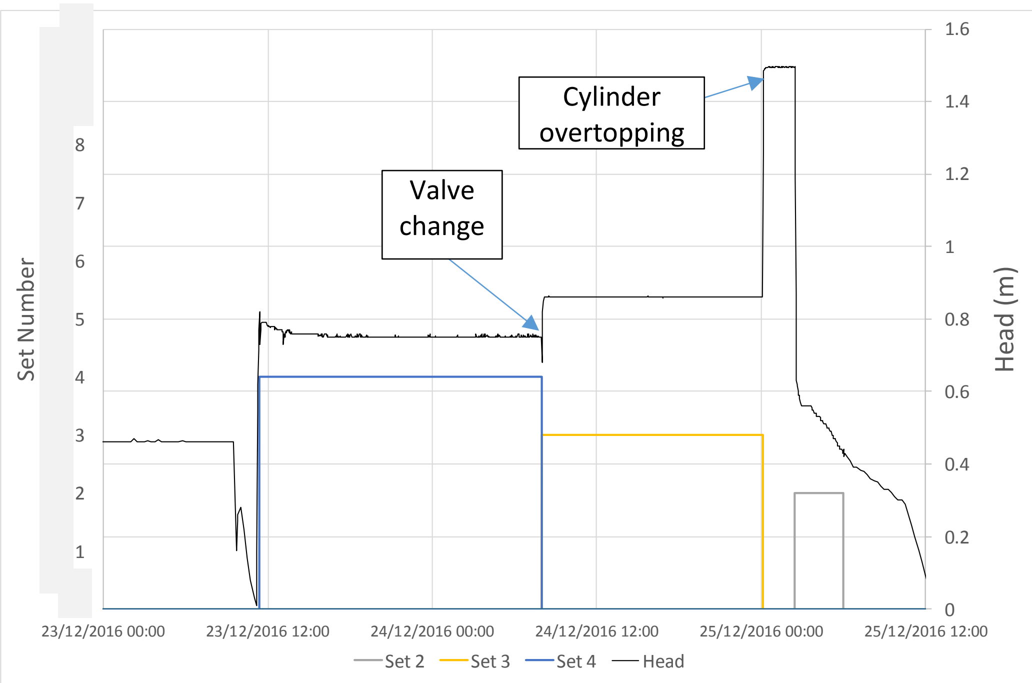


Figure 6-12 – Example of cylinder overtopping

6.3.4. End of Field Advance/Drain Sensors

6.3.4.1. Selecting Suitable Devices

In mid-2016, the project team attempted to find the most appropriate sensing device for detecting water level in the tail water drains. This involved reviewing approaches taken in other agricultural applications and discussion with Pacific Rim Technology Services (PRTS) from Townsville who supplied the PSTs used to monitor the supply. PRTS retail a large range of devices from several manufacturers with several approaches that may have been applicable to this application including:

- submersible PSTs - As used in the supply
- ultrasonic depth sensors
- capacitance depth probes, and
- microwave sensors

The microwave and ultrasonic sensors have the advantage of being non-contact and can be placed above the water so they will not be impacted by any debris in the water. The capacitance sensor uses similar technology to devices used to conduct evaluations of water depth in border check irrigation. However, the sensors available were designed for process control situations (e.g. inside a sugar mill) and were not designed to be exposed to sunlight or rain, they were not compatible with the standard WiSA signals and most had an unknown or high power consumption over and above what the WiSA radio node can supply. The submersible PST will work in this situation but is probably not sensitive enough to detect the very small changes in water level in the tail water drain.

6.3.4.2. Installation of Probes

The original plan at this site was to install three WiSA radios each connected to buried soil moisture probes in two adjacent blocks, similar to what was installed at the Jordan site as detailed in a later section. Denis instead desired to install probes at the end of the field within the tail water drains. This field is set up with a tail water recycling system, and therefore it is not essential that the water flow is shut off immediately when runoff starts. Runoff sensors will provide a better indication that water has reached the end of the field whereas buried sensors are only sensitive to the advancing front in the single furrow where they are installed.

The drainage at this site is complex, block 1 drains sideways from the end of the field into a drain on the left side of Figure 6-6. Figure 6-13 below shows (a) the small drain looking along the end of block 1 and (b) the tail water storage draining blocks 1 and 2. This storage also receives water from a field on the southern side (across the other side of the storage) and is of a significant size (water depth would be slow to respond to runoff) and therefore the drainage sensor would need to be placed in the drain before it reaches the storage.

Blocks 3,4,5,6,7 and 8 drain into a separate drainage channel which travels in the opposite direction towards the north as shown in Figure 6-6 (to the right in Figure 6-6). The water for each block drains into a small culvert for each block or pair of blocks to travel under the downstream headland. Blocks 3 and 4 share a common culvert as shown in Figure 6-14 and therefore runoff can be captured using a single sensor. Similarly blocks 5 and 6 share a common culvert. Blocks 7 and 8 have separate drainage lines but the drain probes are located a short distance apart and can be captured using a single radio node.

Figure 6-13 – Drain at corner of block 1 at Pozzebon site.

Figure 6-14 – Drain sensor installed upstream of culvert at end of blocks 3 and 4 at Pozzebon site.

The 5 drain probes were installed sequentially over the space of months as fields were harvested. The installation dates of the probes are as follows:

- Block 1 4/10/2016
- Block 2 16/01/2017
- Blocks 3&4 4/10/2016
- Blocks 5&6 24/02/2017
- Block 7 1/03/2017
- Block 8 1/03/2017 But no data is available for this block

A continuous record of drain level is available for each block from this installation date to the current date.

6.3.4.3. Sample Data from Drain Probes

The drain probes are soil moisture probes and as such provide a number ranging from 0 - 100 which would normally represent soil moisture if installed in the soil. The level (height) of the probe can be adjusted by the grower to change the sensitivity of the probe to the runoff flow, for example if the probe is located at a lower elevation it might trigger on the first few furrows, but moving the probe higher would mean that it only responds when the majority of furrows are contributing to runoff. Figure 6-15 provides an example of the data collected by the sensors for several irrigations.

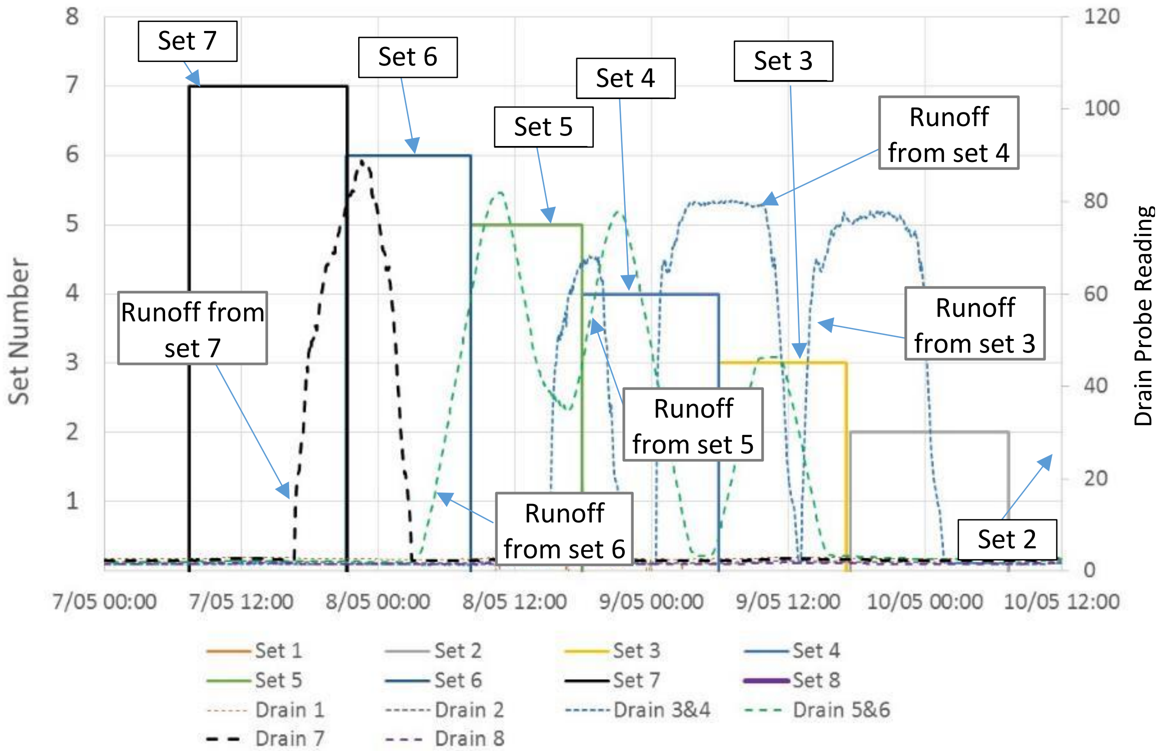


Figure 6-15 – Sample Drain probe data from Pozzebon Site.

In this example, all actions were performed using the automation, but the sensor was not used to automatically switch sets. The data in this plot explained in detail is as follows:

1. 7/05/2017 at 7:23 am, - Irrigation of Set 7 starts
2. 7/05/2017 4:42 pm (559 min after 7 starts) - Drain 7 detects runoff
3. 7/05/2017 9:14 pm (831 min after 7 starts) - Set 7 stops and set 6 starts
4. 8/05/2017 3:07 am (353 min after 6 starts)- Drain 5&6 detects runoff
5. 8/05/2017 8:07 am (653 min after 6 starts) - Set 6 stops and set 5 starts
6. 8/05/2017 3:10 pm Drain 3&4 rises but dismissed as false trigger (may be water backing up from drain)
7. 8/05/2017 4:57 pm (530 min after 5 starts)- Drain 5&6 detects runoff
8. 8/05/2017 5:55 pm (588 min after 5 starts) - Set 5 stops and set 4 starts
9. 9/05/2017 0:27 am (392 min after 4 starts)- Drain 3&4 detects runoff
10. 8/05/2017 5:30 am Drain 5&6 rises but dismissed as false trigger (may be water backing up from drain)
11. 9/05/2017 5:53 am (588 min after 4 starts) - Set 4 stops and set 3 starts
12. 9/05/2017 1:07 pm (434 min after 3 starts)- Drain 3&4 detects runoff
13. 9/05/2017 5:06 pm (673 min after 3 starts) - Set 3 stops
14. 9/05/2017 5:28 pm Set 2 starts
15. 10/05/2017 7:19 am Set 2 stops (no runoff detected)

6.3.5. Conclusion

The system at the Pozzebon site has been progressively installed over the past 18 months and has been working effectively during this time. Denis has been using the WiSA system to control all events on the automated blocks since they were instrumented. The single pressure sensor provides the system with feedback on the working of the system but now, as additional blocks are automated closer to the supply pumps, the system may require a new sensor positioned at a lower level so it can detect lower heads than the present sensor is capable of. The drainage probes provide information on the completion of advance for most events but there are a number of occasions where they fail to detect that water has reached the end of the field but that may be a result of water not reaching the end of the field if the water is cut off early. Denis is satisfied with the system and is looking to expand to other areas of his farm when his finances allow.

6.4. Linton Site

6.4.1. Site setup

The farm (Figure 6-16) owned by Aaron Linton is comprised of three large drip blocks and one small drip block with a combined area of 44.5 ha and eleven furrow irrigated blocks with a combined area of 51.2 ha. The small drip block lies within the area serviced by the valve for block 2 therefore the total area potentially irrigated by the automation system is 53 ha.

The drip blocks are controlled by a WiSA automatic irrigation system and water is supplied from a tail water storage which also receives water from the SunWater scheme channel. The furrow blocks are supplied from two pumps which source water directly from the river.

Pump 1 delivers a flow of approximately 75.3 L/s and supplies blocks 1 and 2 through a pressurised pipeline. Pump 2 delivers water at an average 59.8 L/s to a concrete cylinder at the top of block 5 and supplies the remaining 9 blocks. Both pumps deliver water to separate underground mains systems running along the field headlands.

Figure 6-16 – Satellite image of Aaron Linton's farm.

The buried supply pipeline runs along the river side headland of blocks 3-8 (Figure 6-16) and then down the side of block 8 to supply blocks 9, 10 and 11. Water is applied to each of the blocks along this pipeline and the tail water from all 11 blocks drains into the recycle pit adjacent to the shed. Aaron modified the drainage system partway through 2016 and now it is not clear what proportion of the runoff from blocks 9, 10 and 11 still flows into the drainage pit.

The soil within the Linton property is a silty loam soil with a low infiltration rate once the furrow has consolidated. Measurements conducted in October 2014 and April 2015 on blocks 6 & 7 indicate that long ponding times are required in order to replenish the soil moisture deficit. The low infiltration rate combined with low moisture holding capacity means that these fields are typically irrigated on a 5 to 6 day irrigation cycle or a deficit of 35-40 mm with a low flow rate of approximately 0.6 L/s per furrow. Even with these low flow rates the nature of the soil means that runoff volumes for a typical irrigation may be up to half of the total volume supplied. Anecdotal evidence from Aaron Linton indicated that this infiltration issue could be addressed through green trash blanketing. A follow up irrigation evaluation in January 2016 on a trash blanketed block supported this opinion, with a vast increase in infiltration and therefore reduced runoff.

Table 6-4 contains the characteristics of the 4 drip blocks and 11 furrow blocks. The sizes of the furrow blocks vary from 2.73 ha up to 8.5 ha with an average size of 4.65 ha, and the number of drills (assuming 1.83 m spacing) per block varies from 43 up to 120.

Table 6-4 – Irrigation blocks within Aaron Linton's Farm.

	Block	Max. Length (m)	Spacing (m)	Width (m)	Drills (No.)	Area (ha)
	Drip 1	485	1.83	306	167	14.13
	Drip 2	485	1.83	308	168	14.20
	Drip 3	440	1.83	345	189	14.16
	Drip 4	430	1.83	46	25	1.96
1	Furrow 1	405	1.83	137	75	5.23
1	Furrow 2[1]	417	1.83	212	116	8.50 (10.5)
Pump 2	Furrow 3	407	1.83	79	43	2.73
Pump 2	Furrow 4	422	1.83	81	44	3.32
Pump 2	Furrow 5	464	1.83	106	58	4.80
Pump 2	Furrow 6	435	1.83	95	52	3.93
Pump 2	Furrow 7	392	1.83	102	56	3.81
Pump 2	Furrow 8	346	1.83	104	57	3.58
Pump 2	Furrow 9	592	1.83	112	61	7.09
Pump 2	Furrow 10[2]	796	1.83	70	38	4.67
Pump 2	Furrow 11[2]	630	1.83	120	79	3.29

[1] Drip 4 shares common area with Furrow 2, the area in brackets represents the potential area serviced by the valve in block 2.

[2] The boundary between blocks 10 and 11 was altered soon after installation of the system to better suit boundary of cane ages.

The design for this site represents the automation of the entire farm with the eleven furrow blocks as shown in Figure 6-17 with a total area of 51.2 ha. The site contains 7 risers, some with two valves and others with one valve. Drip block 4, a trial of low pressure drip is located within the area previously serviced by Furrow block 2, if this block is reverted back to furrow at the end of that trial the total area under automated furrow would increase to 53 ha.

This farm already contained a base station prior to the commencement of the project, installed for the drip irrigation. This base station can communicate to the pumps, control and monitoring nodes for the surface irrigation. The pump switchbox for pump 2 is located close to riser 3, therefore this control node was removed and the valve and pressure transducer were wired to the nearby pump control node.

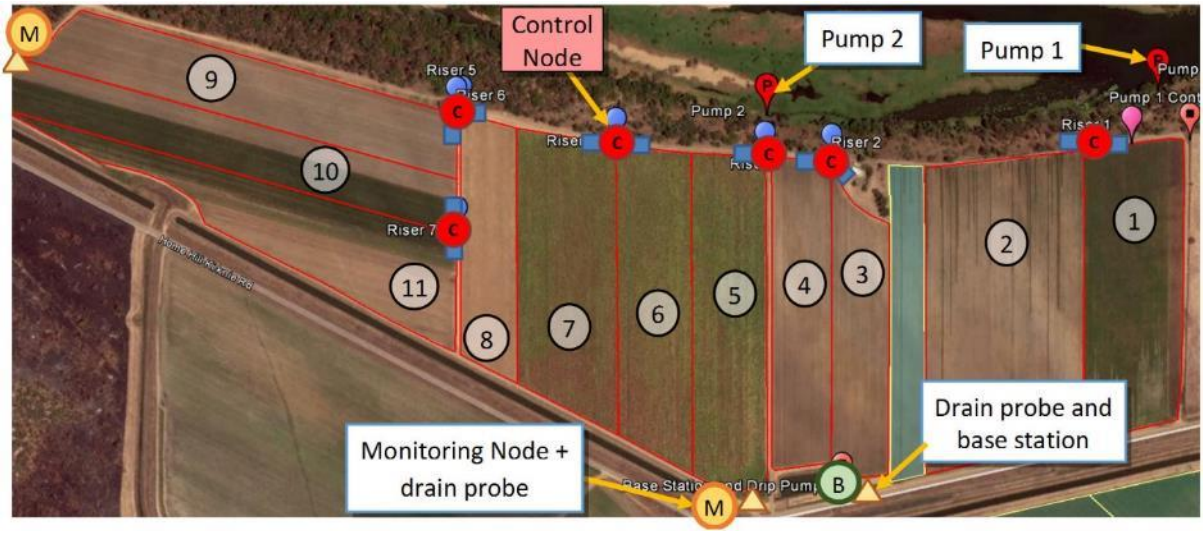


Figure 6-17 – Satellite image Linton site

A summary of the main components of the system as of 1 July 2017 is as follows:

Major Components

- 5 x WiSA control nodes + one WiSA expansion board connected to pump 2 control node.
- 11 x linear actuators and levers connected to Greens and Butterfly valves.
- 2 x WiSA Pump control nodes
- 2 x pressure transducers, one for each pump
- 2 x WiSA monitoring nodes for drains
- 3 drain probes, two connected to the WiSA monitoring nodes and the third to the base station.
- 2 x Siemens Flowmeters for replacement of SunWater meters

Pre-existing equipment

- WiSA monitoring node connected to three soil moisture probes
- Base station within shed
- 1 control node connected to three drip blocks
- Drip pump control board within shed adjacent to base station

The Linton site was the first location where the automation was installed with two valves at one riser (valves 5 and 6) installed in late October 2015 as a prototype and the remainder installed in January 2016. All irrigations on this farm have been remotely controlled and/or scheduled through the automation system since the end of January 2016. Figure 6-18 gives examples of the two types of valves at this site, the Greens valve (a) (valve 3 and 4) and a commercial butterfly valve in Figure 6-18 (b) (valves 1 and 2). Figure 6-19 shows the original installation of the pressure transducer at valve 5.

Figure 6-18 – Valves on (a) cylinder and (b) closed riser at the Linton Site.

Figure 6-19 – Main supply line from pump and initial PST installation (Feb 2016 - Sept 2016) at Linton Site.

6.4.2. Linton System costs

The following costs are based on installing the current system across the 11 furrow irrigation blocks without any prior infrastructure. In reality, Aaron already had a WiSA base station and used an existing computer for control. The costs in this table reflect the commercial rate of installing this system in this field and include the component cost, the commercial mark-up, delivery to site, installation and support. The breakdown of the system as currently installed is as follows:

Table 6-5 Cost breakdown of system currently installed at Linton site

Base Station	(all costs are once off for farm)	**Price**	**Qty**	**Total** (inc GST)
Base station	complete with radio and aerial	3,000	1	3,000
Setup	software, bitmaps, dongle	1,500	1	1,500
Setup	licence ports	80	20	1,600
Computer		1,200	1	1,200
External HDD + UPS	backup	300	1	300
Internet		100	1	100
				$7,700
Pump Sites	(control of both main pumps)			
Pump controller	24 output	3,000	2	6,000
Installation	electrician	500	2	1,000
Pressure transducer	4m external	800	2	800
				$7,800
Flowmeters	(existing meters were outdated and not capable of electronic metering), this cost may not be required at other sites)			
Flowmeter 1	Replacement meter + approved install	4,473	1	4,473
Flowmeter 2	Replacement meter + approved install	5,490	1	5,490
SunWater Charges	Administrative charge	751	2	1,502
				$11,465
Block Control				
Actuator control node	controls 2 actuators	3,000	6	18,000
LINAK Actuator	LINAK LA-35	500	11	5,500
Bracket	Green's valve	300	11	3,300
Bracket fitting	labour - COAR	100	11	1,100
				$27,900
End of Row Sensors				
Advance node	Can connect to any number of probes	3,000	2	6,000
Drainage Probes	SM probes	500	3	1,500
Install	Correct positioning, configuration	500	2	1,000
				$8,500
Commissioning	Physical installation of the base station, field radios, and checking.			**$5,000**
		Per ha		
Total (Entire system)		$1,290		**$68,365**
Without base station (i.e. another farm in radio coverage)		$1,145		**$60,665**
Entire system without drainage sensors (control only)		$1,130		**$59,865**
Entire system without flowmeters (if meters were not outdated)		$1,074		**$56,900**

The base station includes all the equipment associated with the WiSA base station including the computer and the software to communicate to the field nodes. With the exception of the licence ports, this is generally a once off investment as this same base station can communicate to a large number of radio nodes. The pump sites costs include the installation of a radio control board at each of the two river pumps. The original water meters at this site were a mechanical type which did not permit electronic logging. SunWater and LBW are in the process of replacing meters across the Burdekin with electronic meters however the meters at this farm were not due for replacement. Hence the project purchased and installed replacement electronic EM meters at this farm. The block control encompasses the hardware at the top end of the field used to deliver the water to the 11 irrigation blocks. The end of row sensors are the optional system which is used to monitor the completion of the irrigation event. In this case three drain probes were required, one connected to the existing drip pump control board and the other two installed with dedicated WiSA radio nodes. Finally, the commissioning cost of $5,000 is an estimate of the extra cost associated with the installation of the system and configuration of the base station.

6.4.3. Measurements in the supply

This section will describe those devices used to monitor and/or measure the water supply system at the Linton site.

6.4.3.1. Pressure Head

Aaron Linton was already accustomed to the importance of monitoring pressure through his experience with drip irrigation systems. The automated drip system, already existing on this farm, was capable of flushing the filters if the pressure increased above a specified threshold.

In February (24/02/2016) a PST was installed and connected to the pipeline between pump 2 and the riser at valve 5 (Figure 6-19). This installation differs from the Pozzebon site in that a small hole was drilled in the metal supply line and connected to a manometer tube which is connected at the far end to a PST in a protected location. It was felt that installation of the PST directly into the pipe would not be advisable at this point due to the risk of it being damaged. The pressure at this point is equivalent to the water height in the adjacent concrete cylinder at riser 3.

A sample of this data is shown in Figure 6-20 but it is important to note that this data was collected using an early sample PST which did not have adequate range to measure the large range in riser heads. This sensor has since been replaced with a more suitable model.

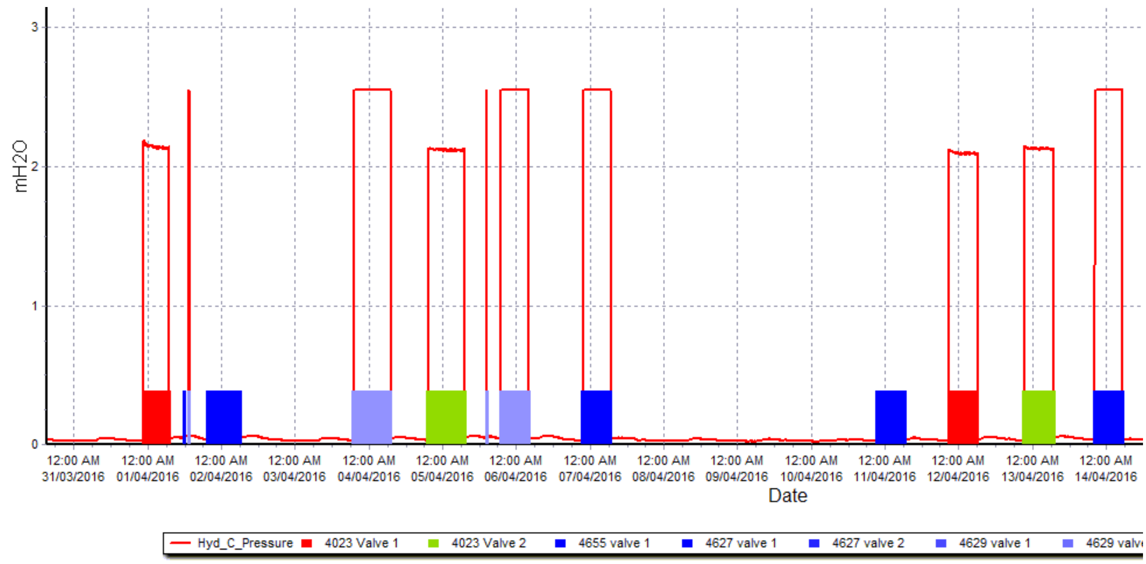


Figure 6-20 – Screenshot of pressure readings from initial PST installed at pump 2.

The original trial PST had a range of 0.25 bar (approx. 2.5 metres) and functioned correctly but it was soon discovered that the water level in this riser operates higher than 2.5 metres when irrigating the valves furthest from the pump. In April 2016, this PST was replaced with a new sensor (Trafag 8473) with a range of 0.6 bar (6 metres). From this point onwards, as shown in Figure 6-21, the PST was able to properly measure the water level. This model of PST is available in ranges of 0 to 0.1, 0.16, 0.2, 0.4, 0.6, 1.0, 1.6 and 2.5 Bar (1 Bar is approx. 10 m of water). The PST for pump 1 was installed after the Siemens flow meter. A plot of all pressure data from the start of the project to the end of January 2017 is given in Figure 6-21.

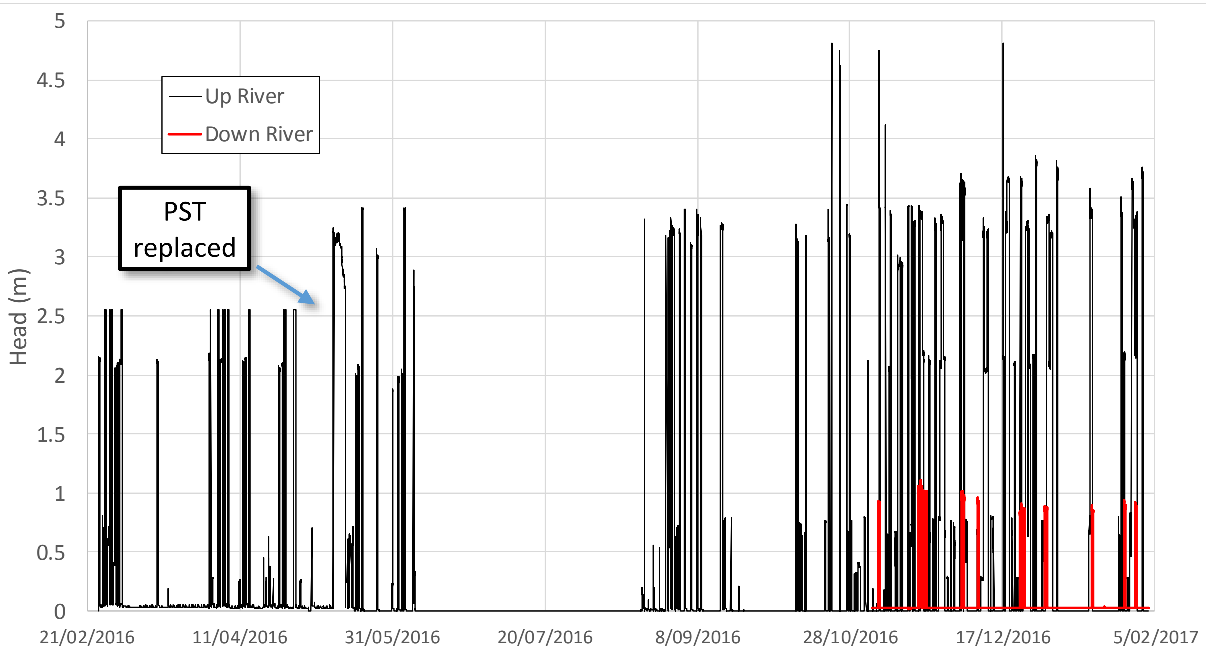


Figure 6-21 – All PST head data at Linton site up until Jan 2017.

Since installation of the PSTs, Aaron has noted that each irrigation block operates at a unique water level and has added alarms to the system to detect when the pressure strays outside that range.

6.4.3.2. Flowrates

Each of the two river pumps at the Linton site were originally connected to Davies-Sheppard mechanical flowmeters which were used by SunWater to meter flows. These meters are based on a propeller connected to a mechanical dial on the face as shown in Figure 6-22. While it is possible to retrofit some modern mechanical meters with electronic readers, there did not appear to be any way to attempt this with these devices. These meters are classed as bulk water, which involves an allocation fee plus a small usage fee of less than one dollar per ML. The nature of pricing for these meters means that it is unlikely that SunWater will be replacing these meters as a priority in the near future. Therefore, the project replaced these meters with two Siemens Magtrans 8000 EM flowmeters (Pump 1 250 mm, Pump 2 200 mm). These meters are similar to that used across the region by Lower Burdekin Water, are far more accurate than the previous meters and most importantly provide a range of electronic outputs.

Figure 6-22 – Original flowmeter at Linton pump 2

Similar to the previous flowmeters, the Siemens meters are installed inline using bolted flanges, unfortunately they are slightly longer and require shortening of the surrounding pipeline. These flowmeters are official metering devices and their replacement requires approval by SunWater (involving a processing fee) and installation and commissioning by an improved agent, in this case a local contractor. The flowmeters were installed in late September 2016 and connected to the nearest WiSA node. The pulse output from the meters can be monitored through any of the WiSA control or advance monitoring nodes. Figure 6-23 shows the flowmeter installed at pump 2 which is connected to the expansion board (just to the right of the figure) which also monitors the pressure and controls valve 5.

The flowmeter for pump 1 is situated below ground 10 m upstream of the riser for blocks 1 and 2. Hence the pulse output from the meter is connected to the control node for these blocks.

Figure 6-23 – New Siemens flowmeter at Linton pump 2.

The factory configuration for these flowmeters is to deliver a pulse for every 10,000 L which is satisfactory for metering purposes but too coarse for monitoring individual events or diagnosing problems with the system. Siemens was instructed to reconfigure these meters before delivery with a smaller pulse but when they were connected to the WiSA radio it become apparent that this had not occurred and as a result the Aqualink software was unable to monitor the flowrate properly with only 1-2 pulses per 5-minute logging interval. The resulting flow hydrograph (example shown in Figure 6-24) produced values ranging from 0 to 163 L/s when the actual flow was close to 60 L/s. Siemens was happy to rectify this oversight and the QLD sales rep visited the site on the 12/10/2016 to reconfigure the flowmeters to provide a pulse every 100 L. This finer pulsing interval means that the system is now able to more accurately measure the flow with time and detect changes in the flowrate very quickly. An example flow hydrograph for the same block irrigated before and after modifying the pulse interval is given in Figure 6-24. It can be assumed that most existing EM flowmeters in the Burdekin would be set at the 10,000 L pulse by default and may need reconfiguration when fitting automation.

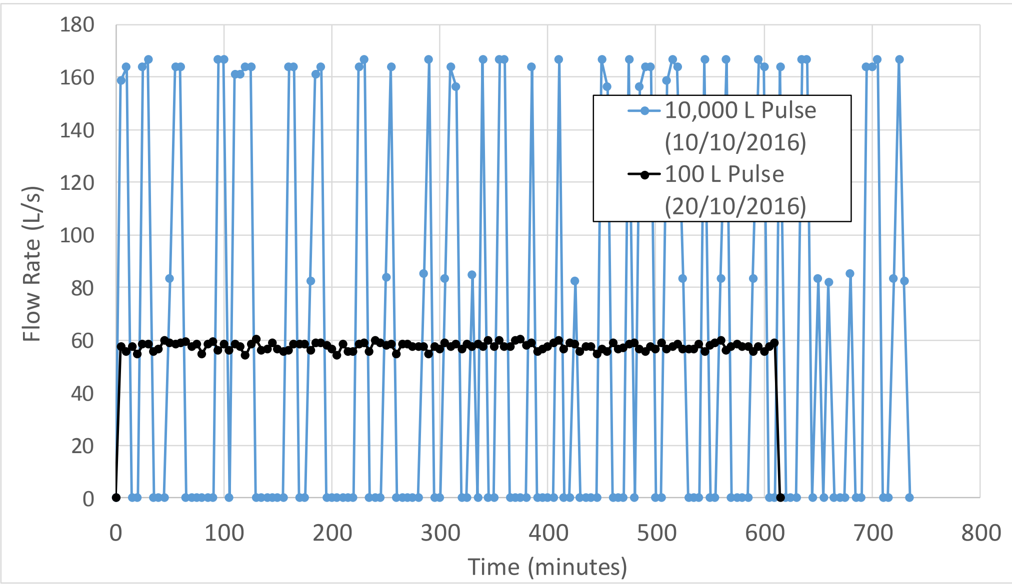


Figure 6-24 – Comparison of flowmeter data with factory setting (10,000 L pulse) and reconfigured setting (100 L/pulse).

Both the flowmeter and pressure transducers are currently set to log data on a 5 minute interval within the WiSA system, but this can be adjusted if required.

6.4.3.3. Sample observations in the supply

When combined, the water flow and pressure measurements provide a complete picture of the behaviour of the supply system. Figure 6-25 shows an example of the data from pump 2 over a 14 day time period. Here it is easy to distinguish the operation of each valve by viewing the pressure head. On almost every night the system has been scheduled to irrigate a number of sets, one at a time, which is different to previously where the grower was restricted to manual operation and no changes during the night.

Normally there is no need for the grower to view this data unless they have been alerted by a warning that the pressure or flow is outside the set tolerances. Viewing this data will also inform the grower if there have been any power outages. Previously with a power outage the pumps would stop and restart when the power returns but there was no record on the time of the outage and related impact of this outage on the volume applied.

There is one concern remaining at this site regarding the head when irrigating block 10 and 11. The maximum head possible is approximately 3.5 metres, governed by the current height of the cylinders. As seen in Figure 6-25, the water frequently approaches this level and any small change in the number of cups in that set may cause the cylinder to overtop. With this data, Aaron is considering making changes to the pipework or increasing the height of the cylinder to rectify this situation.

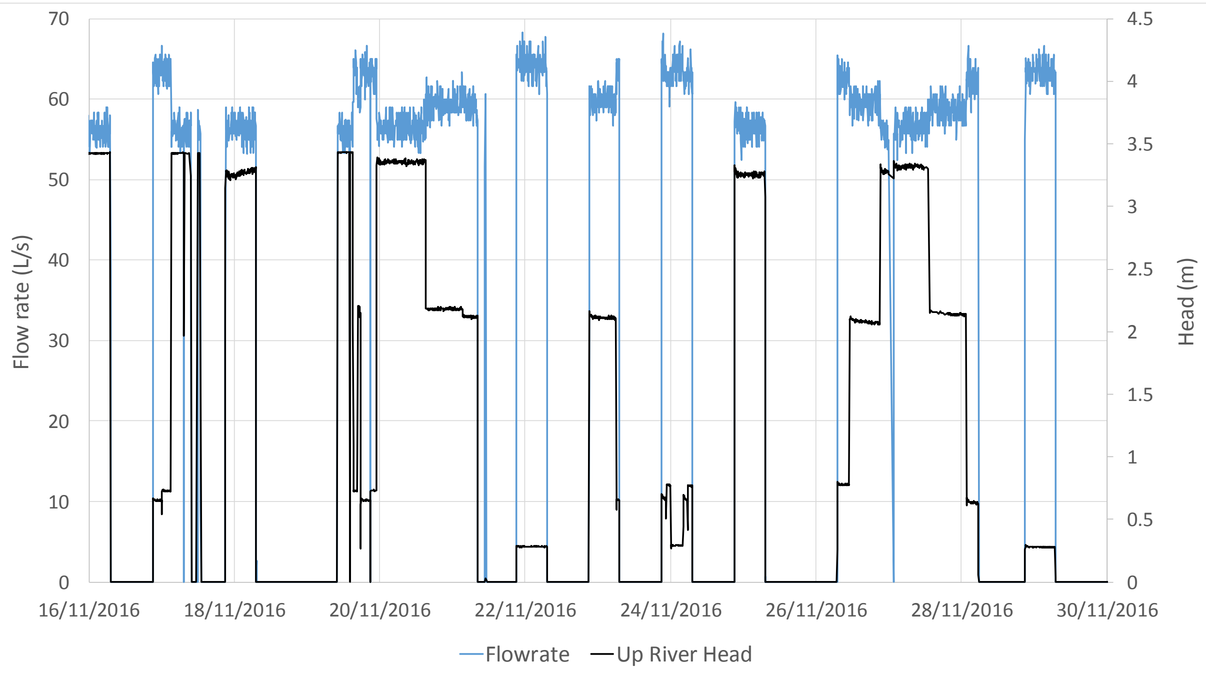


Figure 6-25 – Sample results for flow and head for pump 2 of Linton site.

6.4.4. End of Field Advance/Drain Sensors

6.4.4.1. Testing of Drainage Sensors

The plan at this site was to install a device to monitor either water level or flow within the tail-drain. The main purpose of this measurement was not to determine the volume of flow but to instead serve as a device to detect when runoff commences in the majority of furrows, but not be set off by a single furrow or small number of furrows reaching the end.

The Linton site was the first location where drainage probes were deployed across the three sites. Nothing was known about the range of heights expected in the drain apart from simple observations during field measurements in 2015. The following sections will detail the installation and testing of pressure sensors and drainage probes at the site.

6.4.4.2. Pressure Sensors for Drainage

In early April 2016, two sensitive low range pressure sensing transducers (HOBO 0-4m PST) were installed at the site, one of either entrance to the drainage pit. The PST was positioned just upstream of the culvert to minimise the risk of backwater from the pit and housed within a short length of aluminium tube (Figure 6-26 b) to protect the sensor from trash or mud. It was not known how the drain responds to each irrigation nor the expected water depths, therefore the aim of this deployment was to provide a continuous log of water depths over several irrigation and rainfall events.

The HOBO U20 PST (Figure 6-26 a) is a self-contained absolute pressure transducer. It is designed for remote deployment without the need for any power supply or external logging. These devices are commonly used to measure water levels in bores or tidal fluctuations.

Figure 6-26 – HOBO PST (a) and installed in drain next to culvert for blocks 1-4 (b)

Differential PSTs, such as those used to monitor the water supply, report gauge pressure, i.e. the pressure relative to local atmospheric pressure, hence the reading can be easily converted into a water depth. Absolute PSTs instead measure the pressure relative to an absolute vacuum. Therefore, the HOBO PST is measuring the summed pressures due to atmospheric pressure and water level. Atmospheric pressure changes due to both altitude and weather conditions. Failing to account for changes to atmospheric pressure will result in uncertainty in the measured water level of approximately +/- 350 mm. A third HOBO PST was deployed in the nearby shed to measure the atmospheric pressure so that this could be subtracted and yield the pressure due to water level alone.

The three HOBO sensors were deployed at the site between the 04/04/2016 and 20/11/2016 logging pressure and temperature continuously every 10 minutes during this period. Table 6-6 provides an example of the data recorded by the HOBO PST sited in the drain on the north side of the drainage pit which receives runoff from blocks 1 to 4. Here, the two PSTs are both reading an absolute pressure, but the difference between the drain pressure and barometric pressure is the water depth in kPa. This differential pressure is converted to a water depth using the density of water which includes an adjustment for density based on the temperature. This conversion of differential kPa to metres head is the same as is used in the PSTs in the supply pipelines, but in that case there is no temperature compensation applied.

In the example in Table 6-6, the irrigation of block 2 commenced at 21:37 on the 21/04/2016. The HOBO drain sensor detected water 213 minutes later at 1:10am the next morning. The calculated water depth increased from 5 mm (within the measurement accuracy of the probe) up to 168 mm in a single 10 minute interval.

Table 6-6 Sample data from HOBO drain sensor in drain from blocks 1-4

Time	**Drain Pressure** (kPa)	**Temp**, (°C)	**Barometric Pressure** (kPa)	**Water Depth** (mm)
22/04/2016 0:40	101.478	24.351	101.434	4
22/04/2016 0:50	101.478	24.351	101.434	4
22/04/2016 1:00	101.462	24.255	101.417	5
22/04/2016 1:10	103.04	22.908	101.401	168
22/04/2016 1:20	103.082	23.004	101.385	173
22/04/2016 1:30	103.098	23.100	101.379	176
22/04/2016 1:40	103.101	23.196	101.363	178
22/04/2016 1:50	103.098	23.100	101.335	180
22/04/2016 2:00	103.085	23.100	101.324	180
22/04/2016 2:10	103.111	23.100	101.314	184
22/04/2016 2:20	103.124	23.100	101.308	186
22/04/2016 2:30	103.15	23.100	101.319	187
22/04/2016 2:40	103.172	23.004	101.292	192

A plot of the water depth from the drain on the north side of the tail water storage draining blocks 1-4 is given in Figure 6-27. Here, the level starts close to zero and spikes a few hours after the start of each irrigation event. This data confirms that a single probe located at the correct spot is able to detect the start of runoff for all four blocks on that side of the storage. Over the 8 months this sensor was deployed, the maximum value detected was 500 mm but the majority of runoff events seemed to result in spikes of between 200 and 300mm. Taking notice of the events between the 22/04/2016 and 26/04/2016, the water level rises to 250 mm during the event but only declines to 100mm between events. Therefore, the sensor must be capable of sensing changes in water level over this small 150mm range.

This level of precision is difficult to achieve with most standard PSTs, but could be detected using the same type of PSTs as is deployed at Denis Pozzebon's property in the supply. There are however two problems associated with using PSTs in tail water drains. The first is that differential PSTs require an atmospheric breather tube connected to the sensor. This could be housed inside the WiSA node but would then require that node to be placed close to the point of measurement. The second and more crucial problem is that PSTs need to be submerged in the water and rely on small ports (e.g. bottom of Figure 6-26) to allow the water to enter the sensor. This is likely to be a problem within tail water drains with the quantity of sediment and trash that might flow past the sensor.

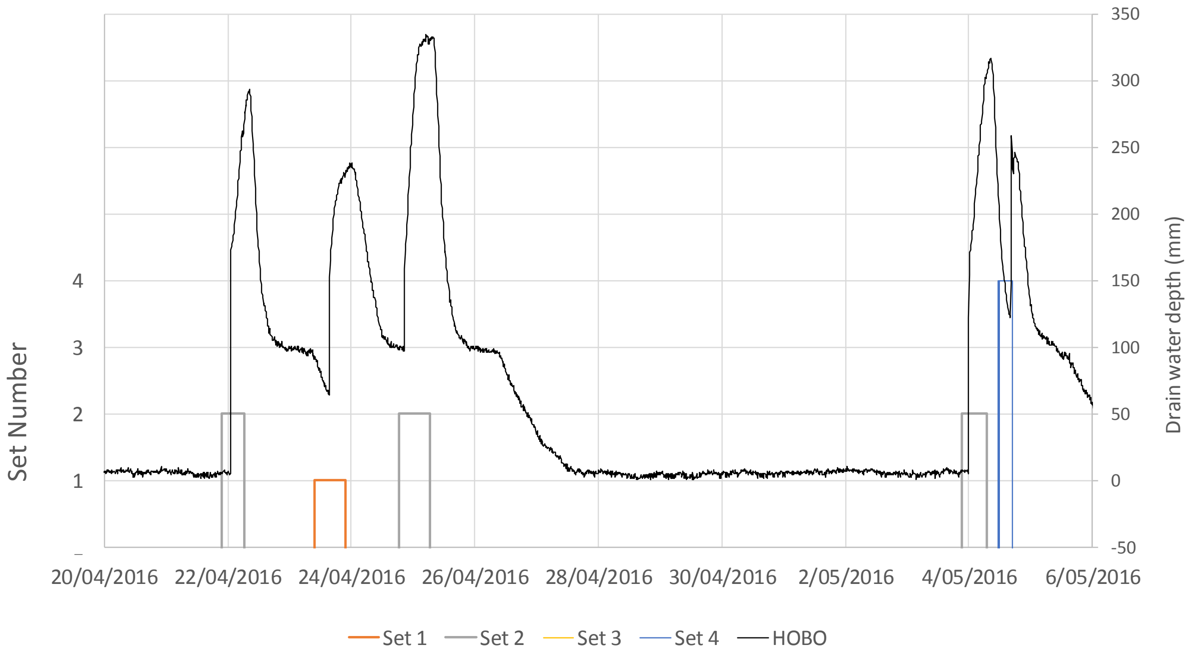


Figure 6-27 – Water level in drain from sets 1 – 4.

6.4.4.3. Testing of Soil Moisture Probes

A number of soil moisture sensors were purchased for deployment as buried end of row advance sensors, as described in the detail following for the Jordan site. These soil moisture sensors respond to the volumetric water content in the area surrounding the probe head. Therefore, it was thought that these sensors could also serve as simple drain level probes.

In April 2016 two soil moisture probes (Decagon GS3 and Decagon 5TM) were installed in the drain entering the southern side of the tail water storage, draining blocks 4 – 11. The two soil moisture probes are shown in Figure 6-28. This was a temporary installation to gather information to assist selection of an appropriate device for level detection. Although not designed nor previously used for this application, the soil moisture sensors provided an indication of water depth over the length of the measuring prongs (approx. 70 mm). These soil moisture probes are capable of measuring a large range of soil moisture contents (the GS3 up to 80% volumetric moisture) and therefore other soil moisture sensors may not perform as well in this application. In this initial test, the 5TM sensor was located on a tomato stake (Figure 6-28 a) and the GS3 was positioned at the soil surface on the side of the drain (Figure 6-28 b).

Although not designed for this purpose, the soil moisture sensor has a number of advantages:

- Simple operation, low likelihood of failure
- There are several models available, so it can be tailored to the application
- Is compatible with almost any potential automation system
- Low power consumption
- Is durable and can handle complete submergence and/or flooding
- No special conditions required, can be simply inserted in the drain.
- Sensitivity can be adjusted simply by raising or lowering the device

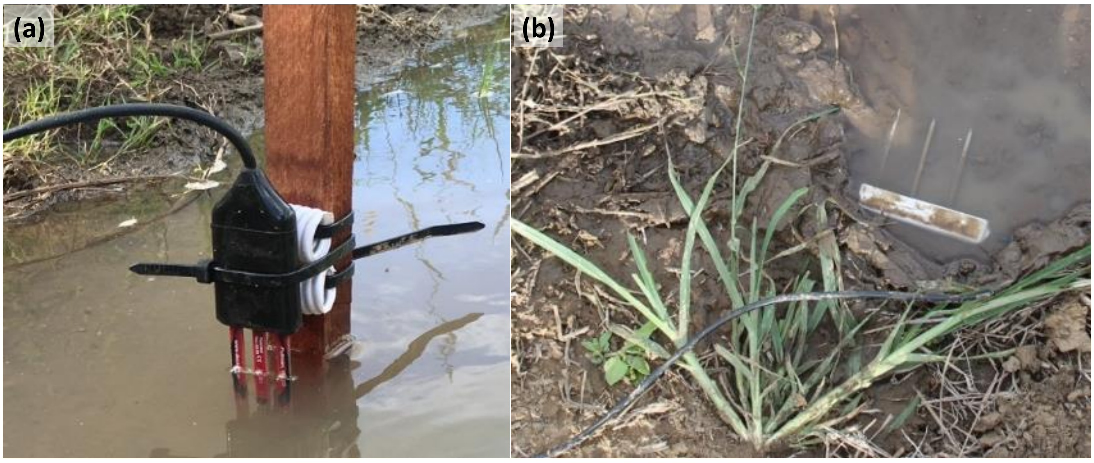


Figure 6-28 – 5TM Soil moisture probe (a) and GS3 soil moisture probe (b) installed as temporary drainage probes

Figure 6-29, represents a screenshot from the WiSA software demonstrating how the sensors behave during irrigation events. The orange line refers to the 5TM sensor and the black line refers to the GS3 sensor. The solid bars indicate the period which the pump was operating, and in each case the runoff commences some hours later. These probes worked successfully for the next few months but struggled to detect runoff from blocks 9 to 11 due to the fact that the water must travel some distance to reach this monitoring point. Subsequently Aaron altered the drainage path for blocks 9-11 and installed a separate sensor at this location.

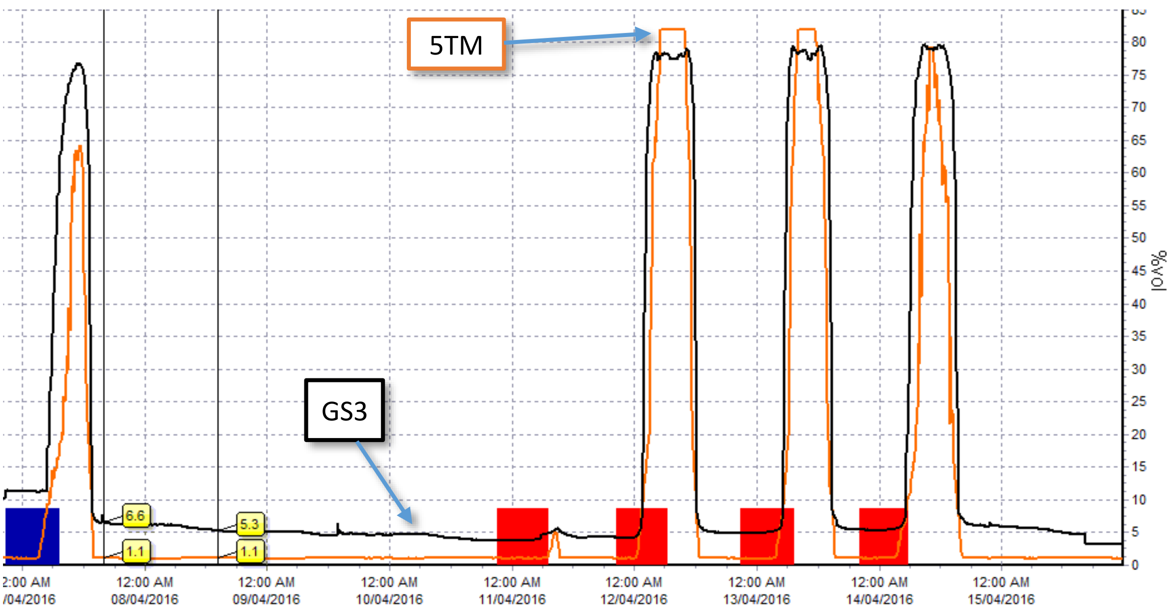


Figure 6-29 – Screen capture of data from temporary soil moisture probes in the WiSA software.

The HOBO PST installed in the drain from blocks 5 to 11, provided a check on the operation of the two temporary drain probes. A comparison of the data in Figure 6-30 shows that the drain probes were able to pick up every event, but missed the initial part of the runoff. This was partly intentional as the drain probe was positioned above the bottom of the drain so that it would only trigger after the majority of furrows were contributing to the runoff. In Figure 6-30 it appears that soil moisture 1 responds to water depths between 50 - 100 mm in the drain at its installed level at that time. This data confirmed the application of the soil moisture probes as effective drainage sensors.

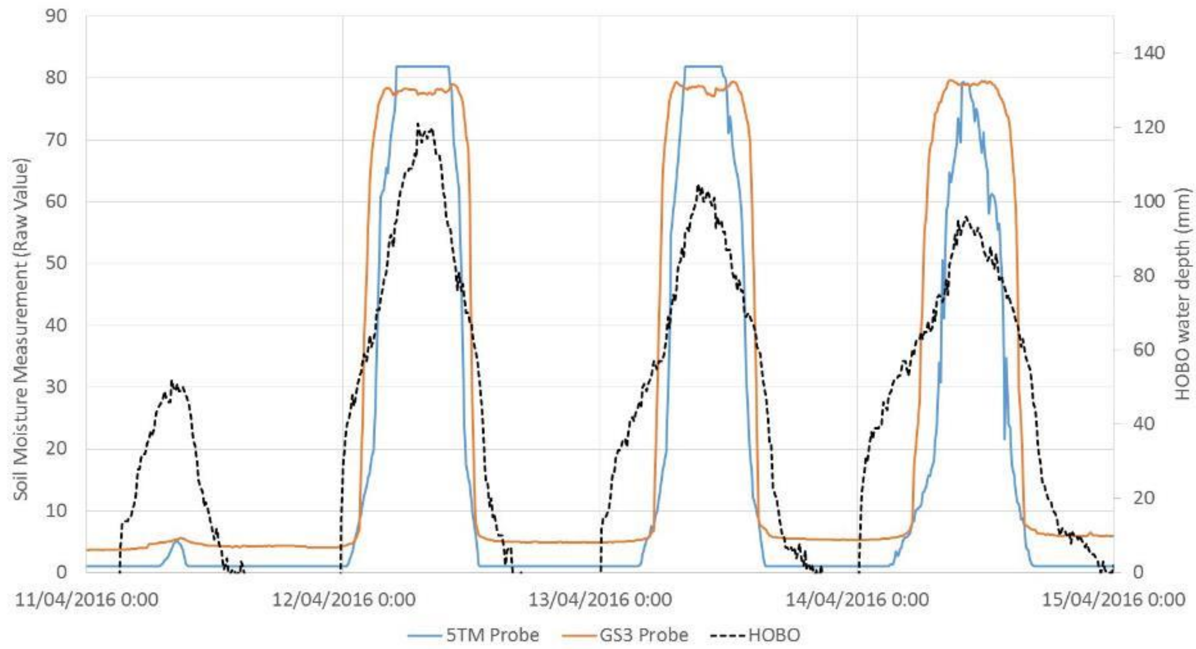


Figure 6-30 – Comparison of temporary drain sensors and a nearby HOBO PST in the drain for sets 5 - 11.

6.4.4.4. Final Installation of Drain Sensors

The final installation of drainage sensors involved installing one GS3 probe at the site of the temporary drain probes (end of block 5) connected to a WiSA node, a second GS3 probe at the end of block 9 and 10 connected to a WiSA node and a MP406 probe in the drain near the base station as shown in Figure 6-17.

The drainage sensors are identical to that used in the temporary installation apart from the fact that they are now housed within a protective PVC container which is vented to allow water to enter without mud or debris causing a problem.

The close proximity of the culvert, draining blocks 1 to 4, to the base station and drip irrigation control board meant that the farmer wanted the drainage sensor to be wired into this board rather than having the expense and concern of a WiSA base station so close to the machinery shed. The machinery shed houses both the WiSA base station computer and the drip irrigation control board. Unfortunately, this control board cannot accommodate the SDI-12 protocol which is required for the soil moisture sensors. The drip irrigation control board was already configured to receive 4-20 mA signals from pressure transducers, therefore ideally the drainage sensors need to communicate via analogue mA signal. There are very few sensors that fit this criterion; one possibility was the MP406 moisture probe which was purchased for use in the Jordan site as a sensor which could be positioned long distances from the WiSA node. In October 2016, the MP406 probe was installed upstream of the culvert at the machinery shed as shown in Figure 6-31.

Figure 6-31 – Install site for drainage probe for blocks 5 to 8, close-up of housing for GS3 drainage probe and install of MP406 probe for blocks 1 to 4.

The location for the MP406 probe was the same as the HOBO PST which had been installed 6 months earlier. This HOBO probe was left collecting data for a further month to validate the performance of the MP406. A comparison between the two devices in Figure 6-32 over the space of 5 runoff events clearly illustrates the ability of the MP406 to detect the rise and fall in water level in the drain.

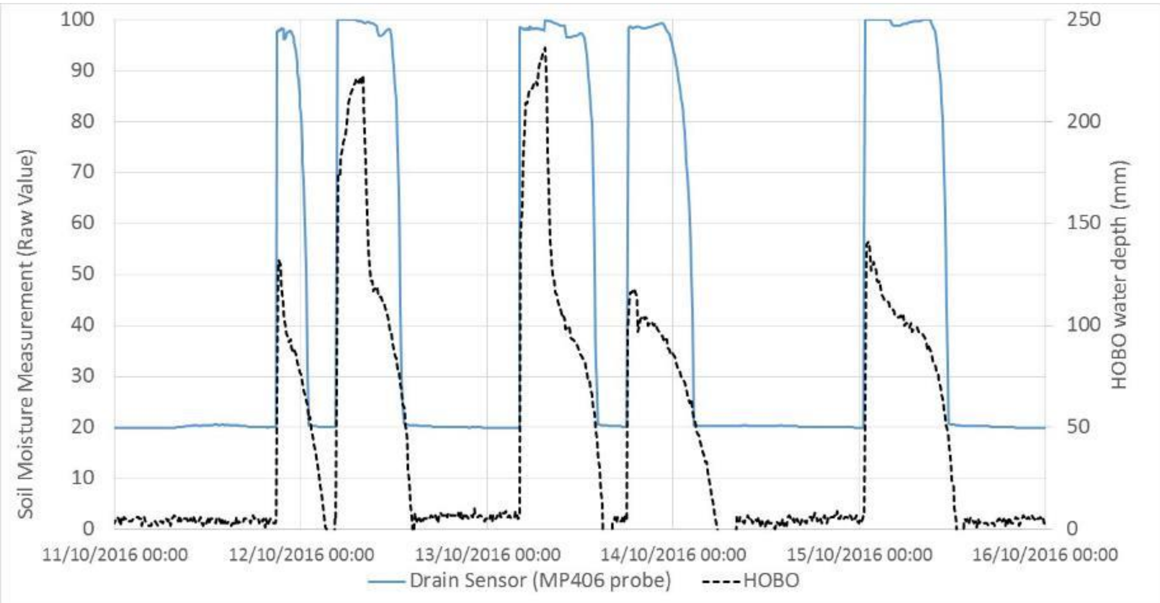


Figure 6-32 – Comparison of Drain Sensor (MP406) and HOBO PST.

6.4.5. Conclusion

Aaron has been using the automation system to conduct every irrigation at this site since installation in early 2016. The data from the measurements between Feb 2016 and June 2017 has indicated that Aaron has drawn the following benefits from the automation systems:

- It is allowing the grower to schedule, control and monitor irrigations remotely.
- It is allowing irrigations to occur during off-peak tariff.
- It is allowing the grower to schedule 2 to 3 blocks to irrigate in one night rather than only one per night.
- It is likely allowing the grower to more adequately fulfil the crop water requirements, previously the cane was probably under-irrigated.

Although records of previous water use at this site are not available, it is reasonable to suggest that the automation system is allowing the grower to apply the water in a timelier fashion where previously the management constraints likely meant that the cane was under-irrigated with a negative impact on yield.

6.5. Jordan site

6.5.1. Site Setup

The Jordan site, owned by Russell Jordan, is located in the BHWSS near the Haughton River, 34km south west from Ayr. Russell has recently purchased this farm and is in the process of evaluating potential upgrades to the irrigation system. The farm is made up of 6 irrigation sets, 5 of which were automated in this project. The 6th set is irregular in shape due to placement of a shed and Russell plans to split this set into two sets sometime in the future. This will require modification to the underground mains pipe by extension to shorter rows at the top of Figure 6-33 which was not completed during the project. This site was selected as a potential candidate for the project as the water is supplied to the entire field from the SunWater channel under gravity with no pumping. This is a good contrast to the other sites and demonstrates that automation is still possible and practical in those cases with no pumping or mains power at the site.

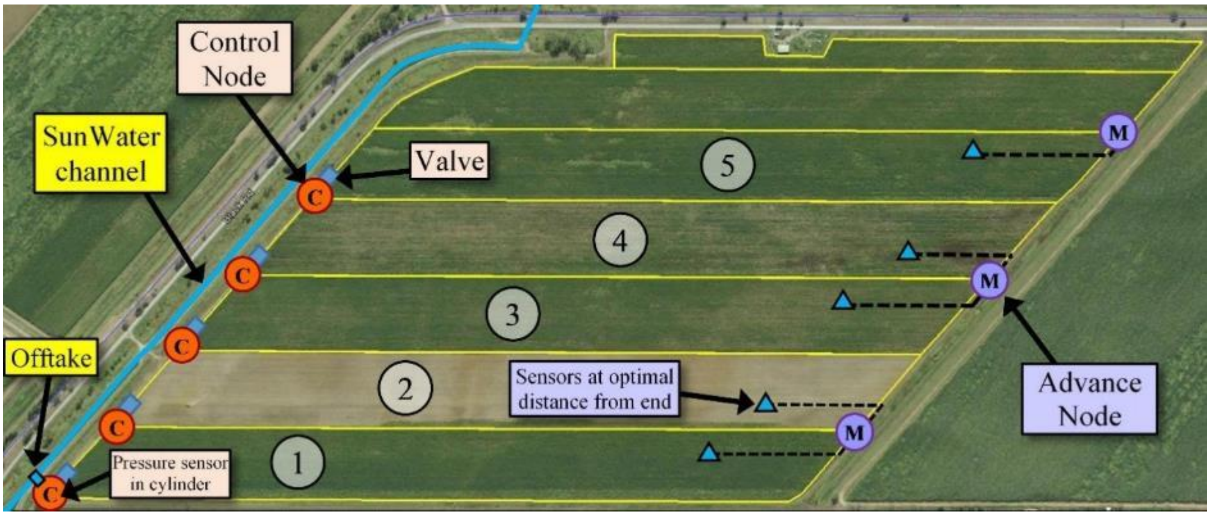


Figure 6-33 – Satellite image of Jordan Site

Water is supplied from the SunWater channel which runs along the top end of the field (to the west). The farm offtake is at the bottom left corner of Figure 6-33 which transports water from the channel through a large diameter concrete pipe to the riser for block 1. This riser is connected to an underground buried pipeline running along the headland. Each of six risers connects to an elbow and valve which irrigates one side of the riser. One possibility at this site is to connect two valves to each of the risers thereby dividing most of the blocks in half and offering the potential of increasing the flow on these furrows. There is insufficient evidence that it would be worth the additional capital cost in making this alteration to the system.

While Russell has plans to construct a recycle pit in the future, at present this farm does not have any ability to capture tail water and hence the desire was to manage the system such that runoff volumes are minimised. It was found that stopping the irrigation once water reaches the end of the field results in excessive tail water and hence through a process of SISCO modelling a distance from the end of the field was selected to install buried soil moisture probes to serve as shut-off triggers.

The field is planted to sugarcane with each block being at a different growth stage and number of ratoons as is common on most sugarcane farms. Blocks 1 and 5 were planted in March and April 2016 respectively. Blocks 2 and 3 were harvested in November and ratooned, while block 4 was harvested at the same time but not ratooned. The areas of each of the blocks are given in Table 6-7 below, with the 5 automated blocks all being approximately the same area and containing a similar number of drills.

Table 6-7 Irrigation blocks at Jordan site

Block	Max. Length (m)	Spacing[2] (m)	Width (m)	Drills[2] (No.)	Area (ha)
Furrow 1	1295	1.52	127	84	16.40
Furrow 2	1285	1.52	127	84	16.60
Furrow 3	1290	1.52	127	84	17.20
Furrow 4	1290	1.52	127	84	16.60
Furrow 5	1290	1.52	116	76	15.10
Furrow 6[1]	1300	1.52	114	75	14.60
Furrow 7[1]	980	1.52	54	36	4.81

[1] Not included in the automation trial

[2] Blocks 1, 4 & 5 were originally on a 1.6m spacing but were replanted to 1.52 during the project.

A pressure transducer is installed within the concrete cylinder at riser 1. This pressure transducer not only provides diagnostics for the irrigation system, it may also serve as an indicator of blockage of the screen at the channel offtake. The channel, at this point, has a heavy weed load and the screen frequently becomes blocked, but Russell currently has no way of checking this other than manual checking, on average twice a day. It is envisaged that the pressure sensor will provide the ability to check for blockages without visiting the site, a blockage will cause a drop in the water level and therefore cylinder head.

The flowmeter at this site is a mechanical type with no possibility of retrofitting with electronic output. The project did investigate the possibility of replacing this meter with a modern EM meter. The offtake pipe from the channel has a diameter of 450 mm, is 30 m long, slopes downward with distance away from the channel and is approximately 2 m below ground surface level when it reaches the first cylinder. The pipeline size, and fact that this pipe was buried, meant that it was hard to justify the cost and difficulty of replacing this flowmeter. For this reason, a temporary Doppler meter was installed in the pipeline as discussed in the following sections.

Prior to the project, Russell Jordan already had a WiSA base station located at his home farm just over 6 km from this farm, beyond the limit of these radio transmitters. As discussed in 7.2.2, the WiSA nodes at this site were configured to route their signals through a pump controller node for a different farm which was approximately equidistant between the farm and Russell's home. A summary of the main components of the system as of 1 July 2017 is as follows:

Major Components of the Automation System

- 5 x WiSA control nodes
- 5 x linear actuators and levers connected to Greens and Butterfly valves.
- 1 x submersible pressure transducers
- 3 x WiSA monitoring nodes for drains
- 5 drain probes. (Various probes have been tested at different times)
- 1 x UniData Starflow meter

Pre-existing equipment

- Base station and PC at Russell Jordan's home
- WiSA pump node at a different farm which is used for a radio repeater station

Temporary components or components installed for Smarter Irrigation project

- Additional end of row probes for testing purposes
- Weathermation weather station
- Elster EM flowmeters
- MultiFurrow Advance Probes (made up of GS1 probes + Arduino board)
- 3 x Davis tipping bucket rain gauges (connected to WiSA Nodes)
- 3 x TDR soil moisture probes (connected to WiSA Node)

The risers at this site were connected to standard 12" butterfly valves with a manually operated wheel and gearbox attached. The gearbox was removed and a short lever was attached to the valve shaft. Russell made these modifications himself rather than using the lever design built for the Pozzebon site. A bracket arrangement was bolted to the pipe flange which then allowed connection of a LA35 linear actuator between the bracket and the lever (Figure 6-34). The LA35 is attached with easily removed pins such that it can be quickly removed and the valve can be manually operated if the WiSA system fails to move the valve. Russell has not had any need to operate these valves manually but the pin assembly also makes it a simple job to remove the WiSA node and actuator prior to burning and harvesting.

Figure 6-34 – Close up of valve and actuator at Jordan site.

The design of this bracket and position of the lever at closure varied between those risers with and without concrete cylinders. Figure 6-35 shows the two different types of riser. Note that the radio node in Figure 6-35.b was later raised and mounted off the top of the concrete cylinder to improve radio reception as the sugarcane grew taller.

Since installation, Russell Jordan has made several small but novel modifications to the system. All WiSA nodes were initially mounted on 2 m Aluminium poles which caused problems as the sugarcane became taller than the radio mast and signal strength declined. In some locations, the 2 m mast was replaced with a 3 m mast. Russell instead built a bracket to mount the WiSA node on the concrete cylinder (Figure 6-36 a) for the two valves at this site with cylinders. Not only does this increase the height of the node to increase radio signal strength but it places the node in a location where it is unlikely to be in the way of machinery. The bracket allows the node to be simply lifted off the cylinder in one action. A second idea is the building of mounts to house the WiSA nodes when they need to be removed from the field prior to burning and harvesting. In the first harvest season, Russell removed the nodes and drove them back to a nearby shed for storage. This caused two problems, firstly that the rough trip may cause connections inside the node to become loose but secondly, if the node is stored in a shed the battery will likely discharge and if left too long will cause damage to that battery. As a solution, Russell built a small concrete pad (Figure 6-36 b) on the side of the headland close to each node so that the node and linear actuator could be quickly moved from the field prior to harvest.

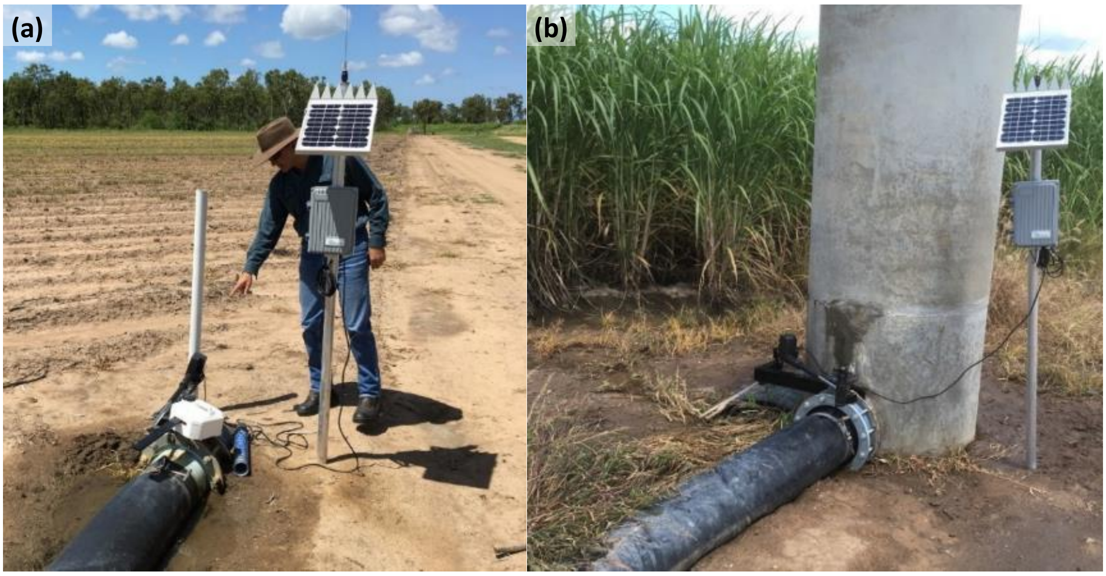


Figure 6-35 – Automated valves at Jordan site, (a) closed riser and (b) open concrete cylinder

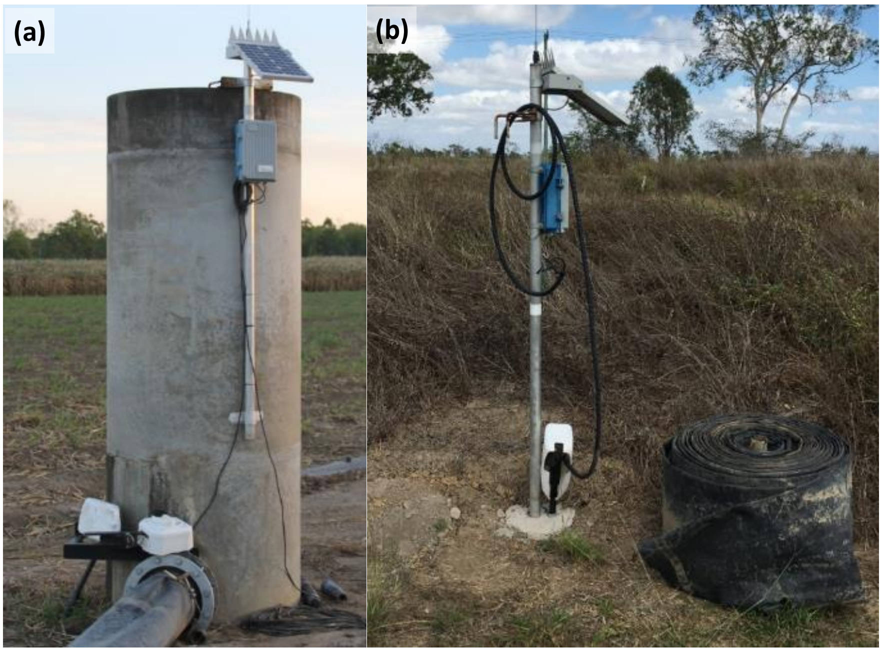


Figure 6-36 – Modifications to WiSA mounts at Jordan site, (a) Bracket to mount WiSA node on concrete riser and (b) storage for node on edge of headland.

6.5.2. Jordan System Costs

The following costs are based on installing the current system across the 5 irrigation blocks without any prior infrastructure. In this case, Russell already has a WiSA base station located at his home and used an existing computer for control. The costs in this table reflect the commercial rate of installing this system in this field and include the component cost, the commercial mark-up, delivery to site, installation and support. The breakdown of the system as currently installed is as follows:

Table 6-8 Cost breakdown of system currently installed at Jordan site

Base Station	(all costs are once off for farm)	**Price**	**Qty**	**Total** (inc GST)
Base station	complete with radio and aerial	3,000	1	3,000
Setup	software, bitmaps, dongle	1,500	1	1,500
Setup	licence ports	80	10	800
Computer		1,200	1	1,200
External HDD + UPS	backup	300	1	300
Internet		100	1	100
				$6,900
Pump Site	(none required)			
Pump controller	24 output	--	0	--
Installation	electrician	--	0	--
Pressure transducer	2m submersible	800	1	800
Starflow meter	Installed for trial purposed only	--	1	--
				$800
Block Control				
Actuator control node	Only able to control one valve due to pipeline configuration	3,000	5	15,000
LINAK Actuator	LINAK LA-35	500	5	2,500
Bracket	Green's valve	300	5	1,500[1]
Bracket fitting	labour - COAR	100	5	500[1]
				$22,200
End of Row Sensors				
Advance node	Can connect to any number of probes	3,000	3	9,000
Drainage Probes	SM probes	500	5	2,500
Install, trenching and cabling	Each sensor is connected to 150m of trenched cable inside conduit	1000	5	5,000
				$16,500
Commissioning	Physical installation of the base station, field radios, and checking			**$5,000**
		Per ha		
Total (Entire system)		$593.90		**$48,700**
[2]**Without base station** (i.e. another farm in radio coverage)		$509.76		**$41,800**
Entire system without drainage sensors (control only)		$392.68		**$32,200**
Without base station + block 6 (96.5 hectares)		$489.12		**$47,200**

[1] in this case the grower installed this himself and therefore no cost was incurred

[2] This reflects the system installed during the project as the base station was pre-existing

The base station includes all the equipment associated with the WiSA base station including the computer and the software to communicate to the field nodes. With the exception of the licence ports, this is generally a once off investment as this same base station can communicate to a large number of radio nodes. The block control encompasses the hardware at the top end of the field used to deliver the water to the 5 irrigation blocks. The end of row sensors are the optional system which is used to monitor the completion of the irrigation event. In this case, three WiSA nodes were required to monitor the runoff without altering the drainage system. Finally, the commissioning cost of $5,000 is an estimate of the extra cost associated with the installation of the system and configuration of the base station and related software.

The total system cost including the base station of $48,700 when split over the 82 hectares of the trial equates to $593.90 per hectare which is by far the lowest cost system of out the three sites.

The final line in this table represents the cost if the sixth set was added to the system by installing one more control node and actuator along with one more end of row sensor. This system would irrigate a total area of 96.5 ha and cost only $489.12 per hectare.

6.5.3. Measurements in the supply

6.5.3.1. Pressure Head

In pumped systems there is a clear link between flow and pressure head and failure to open a valve will cause the head to rise significantly. For gravity systems such as this the pressure head would normally exhibit minimal change over time and between irrigation sets. Despite this anticipated difference it was seen that installation of a PST would still provide valuable data.

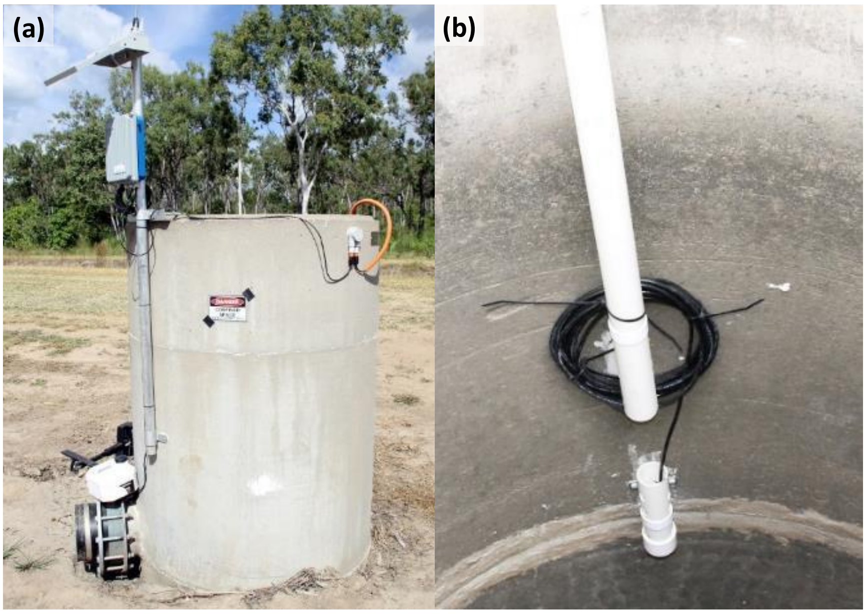


Figure 6-37 – Installation of PST at riser 1 (a) node and cylinder, (b) PST inside cylinder.

A submersible PST (Trafag ECL 0.2A) was installed in the concrete cylinder at riser/valve 1 as shown in Figure 6-37 (b). The PST was sited such that a zero reading on the sensor would roughly coincide with a water level within the cylinder equivalent to the ground level or bottom of the valve number 1 as shown in Figure 6-37 (a). This PST has a range of 0 – 2 metres, 0.5% (10 mm) accuracy and requires an atmospheric breather tube which runs through the attached cable and terminates inside a conduit box on the outside of the cylinder (Figure 6-37 a). The PST is wired into the WiSA node for valve 1 and the data is logged at the specified (currently 5 minute) frequency. Partway through the season there was a failure in this PST due to a manufacturing fault and it was subsequently replaced with a new device under warranty.

Figure 6-38 is a sample of the output from the pressure sensors from the Jordan site with each coloured bar representing a different valve being irrigated. Also visible in this image are the readings from furrow flowmeters installed in two of the irrigation blocks.

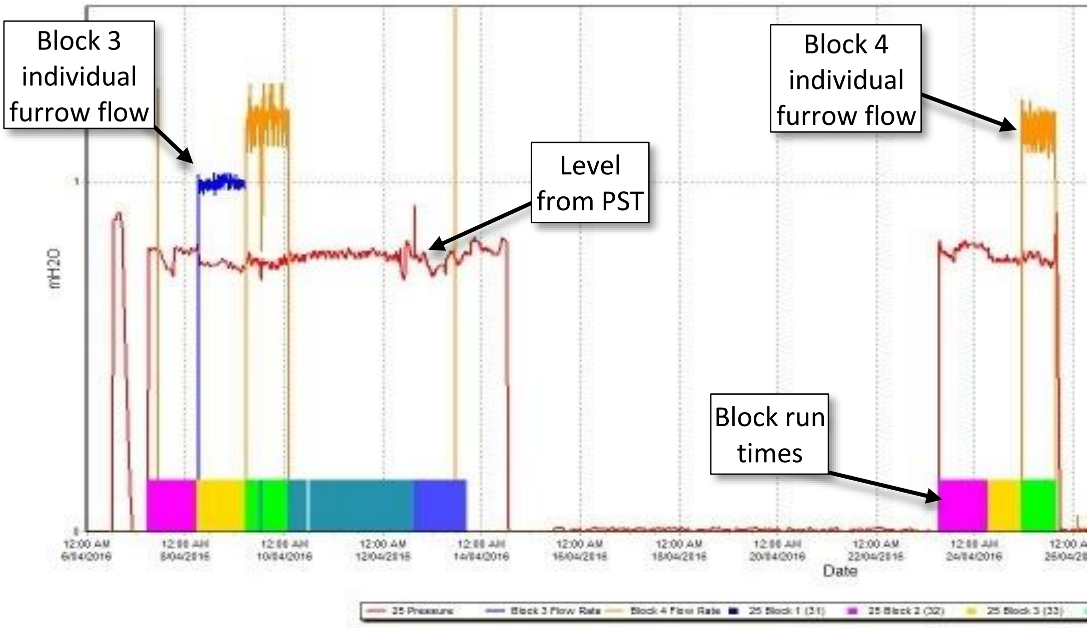


Figure 6-38 – Screenshot of pressure and valve open times at Jordan site

6.5.3.2. Furrow Flowrate

Flowrates were measured at two scales at the Jordan site, individual furrow flow and later whole system flow using a Starflow.

Flowmeters can be installed in individual furrows for irrigation evaluation. The flowmeter chosen for use in furrow irrigation by the NCEA is the Elster Q4000 Electromagnetic flowmeter due to its high accuracy and self-contained power supply. The selected model performs particularly well at low velocities when compared to other flowmeters, the only requirement is that the pipe housing the meter must be completely filled with water with no air. The flowmeters at this site are connected to a length of PVC tubing which terminates in a tank fitting attached to a collection container which can be sealed against the sides of the furrow (Figure 6-39). The large size chosen (80mm and 100mm) means that there will be no restriction to flow and therefore the flow in that furrow will be representative. The flowmeters themselves are very accurate, however as they are only measuring the flow in a single furrow they can only provide an estimate of the total block flow.

In April 2016, two of these flowmeters (in blocks 3 and 4) were installed in a representative furrow and connected to the nearby WiSA radio node through a length of cable. These meters logged continuously and the data was stored in the AquaLink software (as seen in Figure 6-38).

Figure 6-39 – Elster Q4000 flowmeters installed in the furrow (a) side view and (b) front view

6.5.4. Whole Field Flowrate

The furrow flowrate provided by the Elster flowmeter is highly accurate, but can only reflect the water applied to that furrow. Flows will vary between furrows due to size and positioning of cups and the elevation of the pipeline along its length, due to the hydraulic behaviour of these gated pipe systems. A measure of the total system flow provides the average flow across all furrows in the set and is more useful for understanding the irrigation water applied.

The SunWater flowmeter positioned in the main supply for metering purposes is an outdated mechanical propeller based meter with no capacity for external logging or connection to WiSA. In reality, there are doubts over the accuracy of this meter and Russell commented that there have been occasions when the meter is not working and water usage is estimated by SunWater. SunWater are in a process of replacing aged meters but this meter was not an immediate priority and would not be upgraded within the life of this project. The team also investigated purchase and install costs of a new flowmeter but it was deemed to be too expensive for the project and difficult for the grower with the expected downtime.

Several possibilities were investigated but the costs and practical difficulty in replacing the scheme meter meant that a simplified approach was required. Apart from replacing the meter, the next best option would be to excavate around the pipe, drill two holes into the concrete pipe at precise locations and use an insertion style transit time meter. All of these approaches were deemed to be too expensive and time consuming for this project.

Another approach was suggested, the use of Unidata Starflow which could be installed in the pipeline with no modification to the system whatsoever. Starflow meters measure the water depth using an internal PST and water velocity using the sonic Doppler approach. These meters are designed for use in open channels where the flowrate is a function of both the water depth, which can be used to infer cross sectional area, and the velocity. They are equally useful in closed conduits flowing at low heads and velocities less than 4.5 m/s.

Doppler based flowmeters are less accurate than sonic transit time or EM flowmeters, but this device was deemed to provide satisfactory accuracy for the purpose of connecting to the automation system. The major advantage of the Starflow was the low cost and minimal system downtime. Replacement of the scheme meter would require complete excavation of the supply pipeline which is situated 2 metres below ground level. The Starflow was simply fixed to the internal wall of the supply pipeline before it enters the first cylinder using an expanding collar as shown in Figure 6-40.

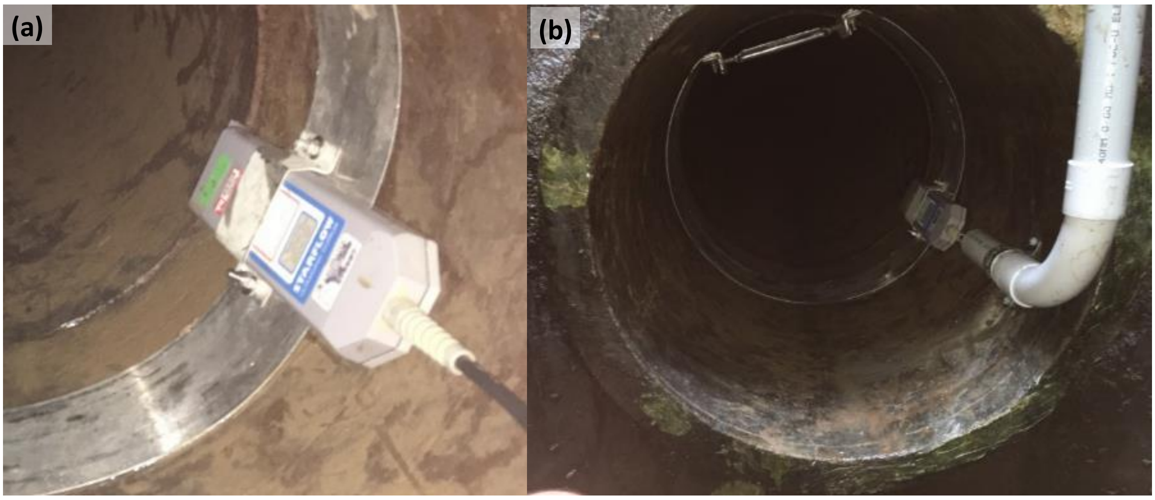


Figure 6-40 – UNIDATA Starflow installed inside the supply pipeline before entering the first cylinder.

The Starflow is normally designed to record the data to an internal logger which can be downloaded on 2-3 month intervals by visiting the site. Fortunately, these devices can be also configured to provide an SDI-12 output which is the same format as the digital soil moisture devices such as the Decagon GS3 and 5TM sensors. The Starflow was configured to provide the following output through SDI-12 at a 5 minute logging interval:

- Water Depth (range of 0 - 2 metres)
- Temperature (degrees Celsius)
- Velocity (set to zero inside the Starflow if the water depth is less than 1m)
- Flowrate (calculated from velocity by Aqualink)

The temperature is used as a diagnostic to ensure the device is functioning correctly as it provides a continuous data signal regardless of the presence of water depth or water flow. The Starflow tends to record strange and oscillating velocity values when it is not submerged in water, these raw readings would cause havoc in the automation system. For example, an extreme peak might set off alarms that there is a leak in the system. The Starflow is positioned close to 2 m below ground surface, and when the flow is operating, the level in the cylinder is usually above this ground surface. As a result, flows to the field usually only occur when the depth measured by the Starflow is at or above 2 m. The Starflow was reconfigured to report a zero velocity, and therefore zero flow, if the depth is less than

1 m due to the fact that the Starflow is positioned close to 2 metres below ground level and the other PST is positioned at ground level. An example of the water level data from the two devices is shown in Figure 6-41, here the PST registers a head of 0.8 m while the Starflow indicated 2 m during the irrigation. In this case the channel offtake is closed and the water level drops quickly at first and then slowly after the level in the cylinder drops below ground level. The water level measured by the Starflow slowly declines from 1.1 m to 0.82 m over the space of 3 days while the PST indicates that water is below ground level and therefore below the valve outlets. A closer inspection of the initial decline in Figure 6-41 (b) shows an approximate 1.7 m difference between the two levels which indicates that the Starflow sensor is 1.7 m below the PST. These results indicate that the value of 1.0 m for the minimum level in the Starflow is sufficient.

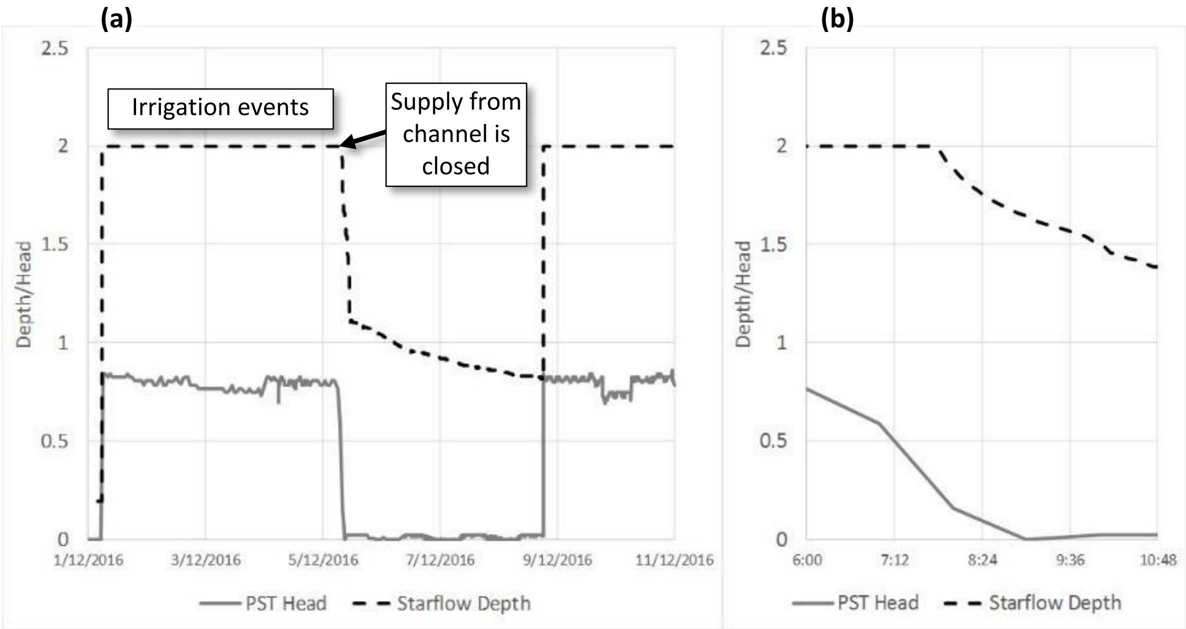


Figure 6-41 – (a) Comparison of water depth from Starflow and measured by PST in cylinder and (b) close up of water level shortly after supply is closed.

Normal flowmeters such as the one discussed earlier at the Linton site log cumulative flow over time, resulting in a steady trace with little or no oscillations. The Starflow is different in that it measures and reports an instantaneous velocity and flow from a short measurement. The turbulent nature of water flow means that the resultant flow data might appear to exhibit a large amount of scatter but this is merely a result of the way in which the data is logged. An example of the data from the Starflow and independent PST is given in Figure 6-42. The raw flow data contains some oscillations over the small time scales, but when averaged out over multiple readings is relatively stable. This averaging or smoothing can be performed inside Aqualink.

In Figure 6-42 the flow changes and there is a small change in the head from the PST every time a new valve is opened and closed with the switching between sets. Also visible in this graph is a period of time when the channel offtake was left open with all valves shut, here the reading given by the PST will be equal to the level in the supply channel.

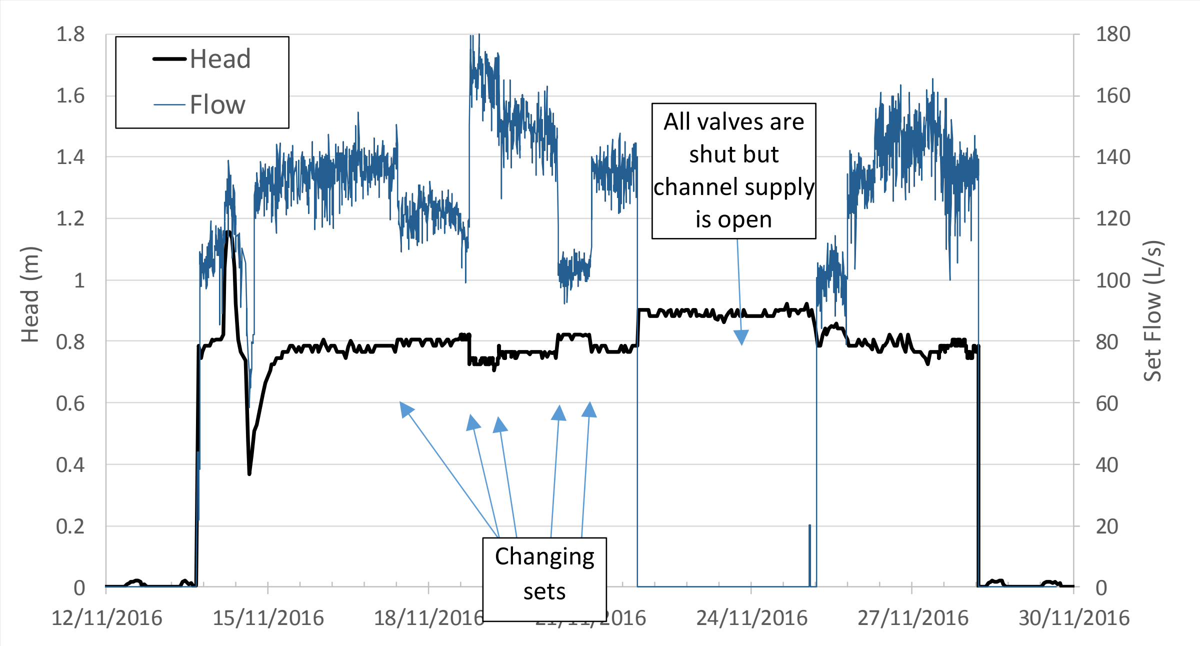


Figure 6-42 – Example of flow and head data at Jordan site.

6.5.5. Sample Observations

It appears from the data collected thus far that the water level in the SunWater supply channel is constant most of the time. A constant water supply level is crucial to ensure reliable and predictable flows onto the farm. However, on the left side of Figure 6-42 and shown in greater detail in Figure 6-43 there is a period of time during an irrigation when the water level in the channel increased by approximately 0.3 m above normal and subsequently drops lower than the normal level. This fluctuation, particularly the drop in the channel, has a direct impact on the flow into the field. The expected flow for block 1 is close to 110 L/s but drops to 70 L/s due to this channel level drop. A lower flowrate will slow down the progress of the irrigation and require the farmer to irrigate for a longer time to get the same result.

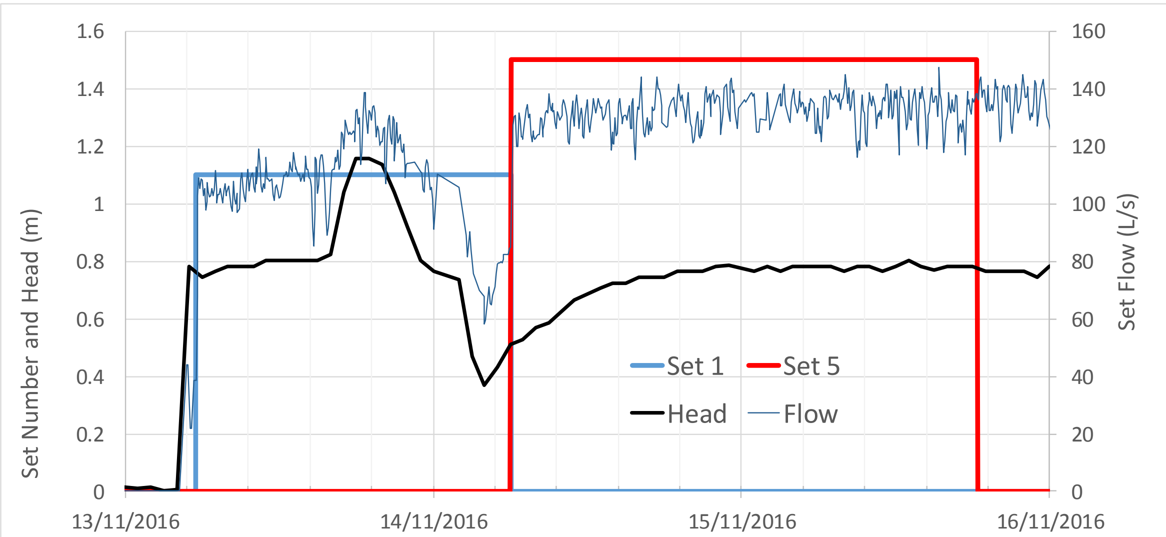


Figure 6-43 – Impact of Supply channel level on irrigation flowrate.

A closer analysis of the flow and head data from this irrigation event on the 13/11/2016 for block 1 gives us an idea of the impact of a drop in head in the channel on the flowrate. Figure 6-44 shows a scatter plot of the flow vs PST head for this irrigation. There is a strong correlation between the two sets of measurements, the slight variation from the curve would be due to the slight oscillation in the flow measurements.

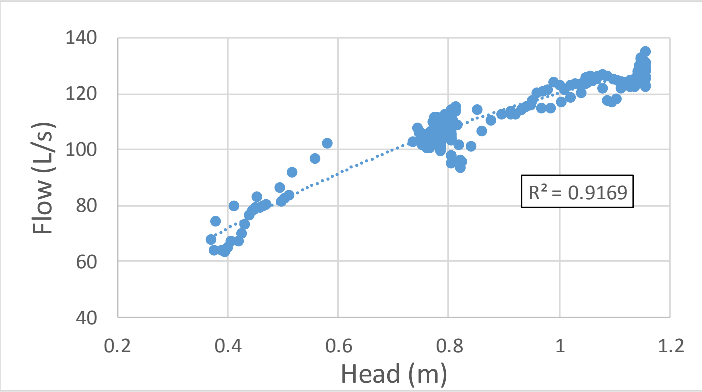


Figure 6-44 – Relationship between flow and head for Block 1 (13/11/2016 – 14/11/2016).

During some times of the year, there can be a build of weed in the channel which blocks the farm offtake grate, and is believed to have a detrimental impact on the flowrate. It is natural to expect that a partially blocked offtake grate will lead to reduced flows and also have an impact on the head within the cylinders. This issue has not been investigated at present but will be considered over the next few months during the R&D for Profit Smarter Irrigation project.

6.5.6. End of Row Sensors

At this site, the grower was particularly interested in end of row sensors for deciding when to switch blocks and/or cut the inflow. In some cases, such as for the Linton site, a drain sensor or sensor positioned at the edge of the field will be sufficient. However, the characteristics of this site, notably the flows used, no recycle pit and the long field lengths mean that these advance detection sensors need to be placed some distance up the field from the tail drain. Soil moisture sensors were chosen for this task because they can be buried deep enough to avoid damage from machinery and provide a continuous signal rather than a simple wet/dry signal.

With consultation with the farmer it was decided that the end of row devices would be connected to WiSA radios which needed to be positioned outside of the paddock at the tail drain and close to existing drain culverts so they were not a problem for machinery movement or slashing. Three WiSA radios were installed at the bottom end of the field (Figure 6-45.b), each one servicing two blocks (1 & 2, 3 & 4, 5 & 6) as shown in Figure 6-33. A number of different devices have been tested as outlined in the following subheadings.

6.5.6.1. Test A - Digital Soil Moisture Probes at end of field

The first round of testing involved installation of two robust, digital soil moisture probes, the Decagon 5TM and the Decagon GS3 (Figure 6-45.a). Both probes are capacitance type probes with a larger sensing volume than traditional capacitance probes. Both of these probes communicate via the SDI-12 protocol which involves sending a string of numbers containing a sensor ID, soil moisture value and temperature value. The SDI-12 protocol allows connection of up to 10 sensors to a single set of 3 wires (power, ground and data) providing that wire is no longer than 200 feet (according to the SDI-12 standard).

The first round of testing involved installation of probes in blocks 2, 3 and 4 positioned 50 metres from the tail drain and 20 rows inside the block. It was decided that 20 rows inside the block would be sufficient to avoid the end fluming cups which may have a higher or lower flow than the average or behave differently. For example, a WiSA radio was positioned at the end of the field at the corner of blocks 3 and 4. A cable was connected to the radio and ran 50 metres up along a laneway between the blocks. From this point the cable was joined to two lengths of cable, one running 20 rows across into block 3 and the other 20 rows across into block 4.

The wiring and probes were temporarily installed in April 2016 as it was not possible to trench into the mature cane. The installation involved excavating a small hole and pushing the probe horizontally into undisturbed soil approximately 150 mm below the soil surface in the watered furrow. The distance of the probes from the radio (> 85 m of cable) was beyond the recommended distance for the SDI-12 communication protocol but there did not appear to be any problems with this configuration.

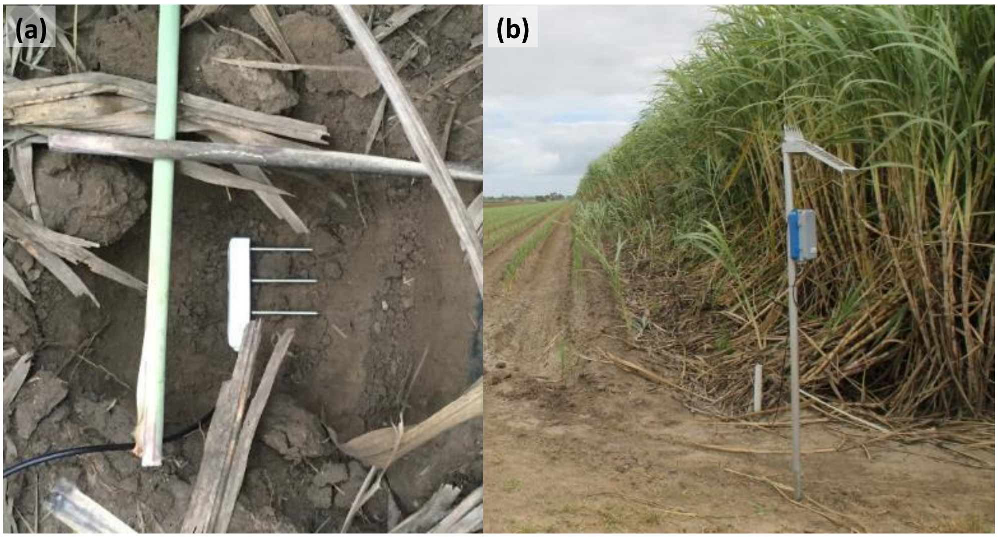


Figure 6-45 – (a) End of row GS3 probe and (b) end of row WiSA radio node between blocks 5 and 6.

Figure 6-46 provides a sample of the data collected from these first set of advance detection probes showing the time that the irrigations took place and the resulting increase in soil moisture detected by each of the probes. The probes are located beneath the furrow and so should experience a sudden increase in soil moisture almost immediately after the water arrives. The value of the y axis is the soil moisture value detected by the probe, calculated from literature given by the probe manufacturer. This soil moisture value is not of any use for irrigation scheduling as it is a single probe at a single location but the presentation of this data as soil moisture provides a good check that the probe is working correctly. Between 5/04/2016 and the 3/08/2016 these three sensors were successfully triggered by every event in those three blocks. This data proves that a single soil moisture probe installed at the correct location is able to detect the water advance moving down the furrow.

The graphs also show some peaks in April that did not coincide with an irrigation event. Data collected by the BPS weather station which is located on this farm measured 10 mm on the 15/04/2016 and 9 mm on the 21/04/2016, which explains these two sudden increases.

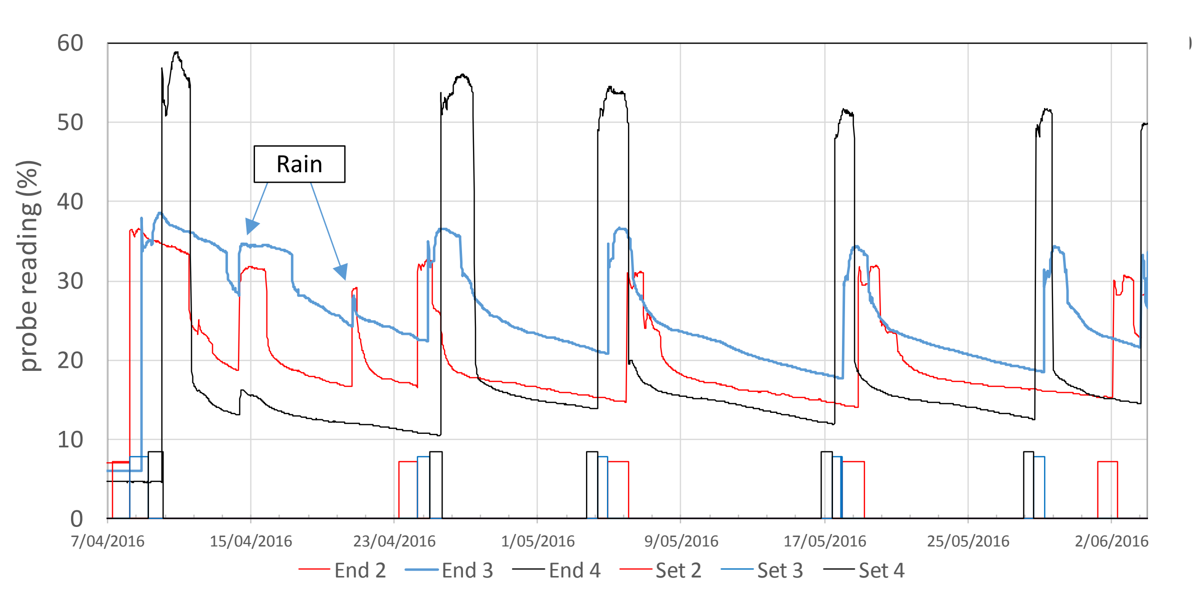


Figure 6-46 – Data from end of field sensors in sets 2, 3, & 4.

During this initial testing, the logging interval was set at 30 minutes which was reduced (smaller interval between measurements) for the subsequent installations. As a result, it was not possible to tell how quickly the probes responded to each wetting event. As seen in Figure 6-46 there is no standard “dry” or “wet” soil moisture, what is important is that the probe experiences a distinct increase in soil moisture which can be easily detected. The typical values detected by the three probes were as follows:

Block 2: Low (6.9 – 16.6) increase suddenly to wet (23.3 – 36.4), aver 16.6% increase
Block 3: Low (6.09 – 17.7) increase suddenly to wet (29.7 – 38.0), aver 15.4% increase
Block 4: Low (4.6 – 13.8) increase suddenly to wet (47.5 – 57.0), aver 40.7% increase

For these sensors, a trigger level of approximately 20% soil moisture appears to be sufficient, that is that a rise above 20% signifies that the irrigation advance has arrived. This is most likely too simplistic, and the control software should be instead looking for an increase in value but it is easier to specify a trigger value than a percentage rise.

6.5.6.2. Test B - Digital Probes at Longer Distance

Through a combination of observations, farmers experience and in-field measurements it was determined that the advance detection probes would need to be relocated further from the end of the field to give sufficient notice to the system to trigger the end of the irrigation. According to the SDI-12 standards, these sensors were already too far away from the WiSA radios. However, there was some indication from the probe suppliers and WiSA technician that it should be possible to stretch the length of these cables further. Therefore, a test was conducted using the WiSA radio at the bottom of blocks 1&2. Here a cable, of total length of 400 m (40 m across and 360 m up from the end of the field) was connected to a GS3 SDI-12 probe installed as previously mentioned. This same radio was also connected to a probe within block 2 installed using the distances in Test A.

This probe was installed on the 30/06/2016 and removed on the 15/09/2016. The probe was still able to communicate with the WiSA radio, but this communication was intermittent as shown in the sample data plotted in Figure 6-47. Here the reading is realistic but jumps to zero whenever it fails to communicate with the sensor. During this 3-month test, there were periods with few failures and other periods with large numbers of failures. Furthermore, it appears that the failure in this sensor had an impact on the other SDI-12 sensor connected to the same radio on the shorter length of cable, the one in block 2. This test has shown that the SDI-12 sensor cannot provide reliable measurements when connected to a long length of cable.

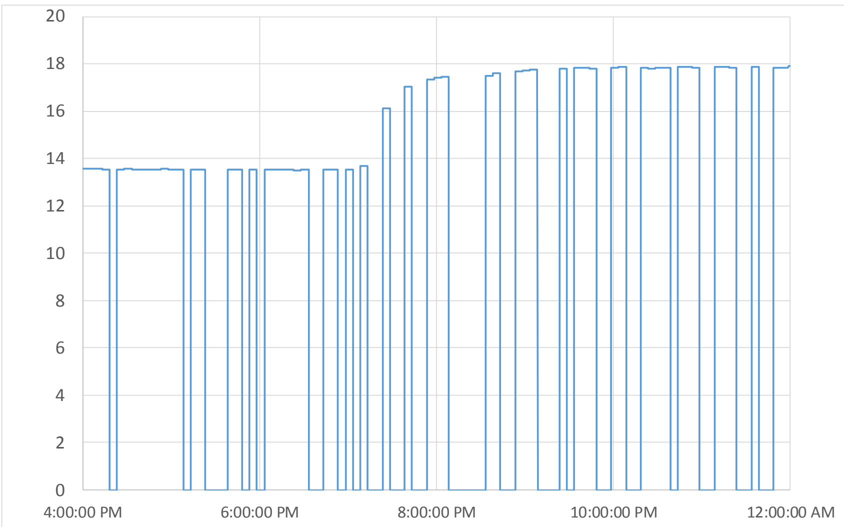


Figure 6-47 – Readings from SDI-12 Sensor with 400m cable in Block 1.

6.5.6.3. Test C - Analogue Probes

The failure of the SDI-12 sensor at the longer distances required the project to look to other potential solutions for measuring soil moisture. There were two main contenders; the MODBUS protocol and the 4-20 mA analogue signal. Most high-end soil moisture probes tend to be SDI-12 while the inexpensive probes tend to be analogue voltage. Analogue voltage would be theoretically worse than SDI-12 in terms of cable distance, the voltage drop caused by the cable would be of simular or even larger magnitude than that of the sensor itself.

One alternative signal type is 4-20 mA, which theoretically should outperform the voltage and SDI-12 sensors in terms of distance. One example of a 4-20 mA sensor is the MP406 soil moisture sensor by ICT international. This sensor is available in both a voltage (more commonly used) and 4-20 mA model. Several MP406 sensors were purchased for installation at this site. The WiSA radio can take up to four 4-20 mA probes using the four analogue output/input ports. There does not appear to be standard limits for the length of cabling allowable for these probes, but it is largely a function of the cable quality. The 4-20 mA signal measured by the WiSA radio is converted to a soil moisture value using an equation fitted to the non-linear calibration curve provided by the manufacturer.

The MP406 probes were installed approx. 150 mm below ground surface on the side of the furrow against the crop row. The probes were installed on the side of the furrow so that there would be increased likelihood that the roots would extract the moisture between irrigations. The data from this testing period and the corresponding irrigation times for block 1 are shown in Figure 6-48. Once again, the probe was able to detect the advancing water front for each of the irrigations during this three-month period. The rise on the 30/09/16 is the result of a 27 mm rainfall event. Smaller rainfall events do not have any impact such as the 5.2 mm and 5.6 mm events which occurred on the 5/11 and 13/11 respectively. The MP406 probe performed well with cable lengths of both 400 m and 200 m and therefore these sensors were chosen as the preferred device for installation in all blocks growing cane from September onwards.

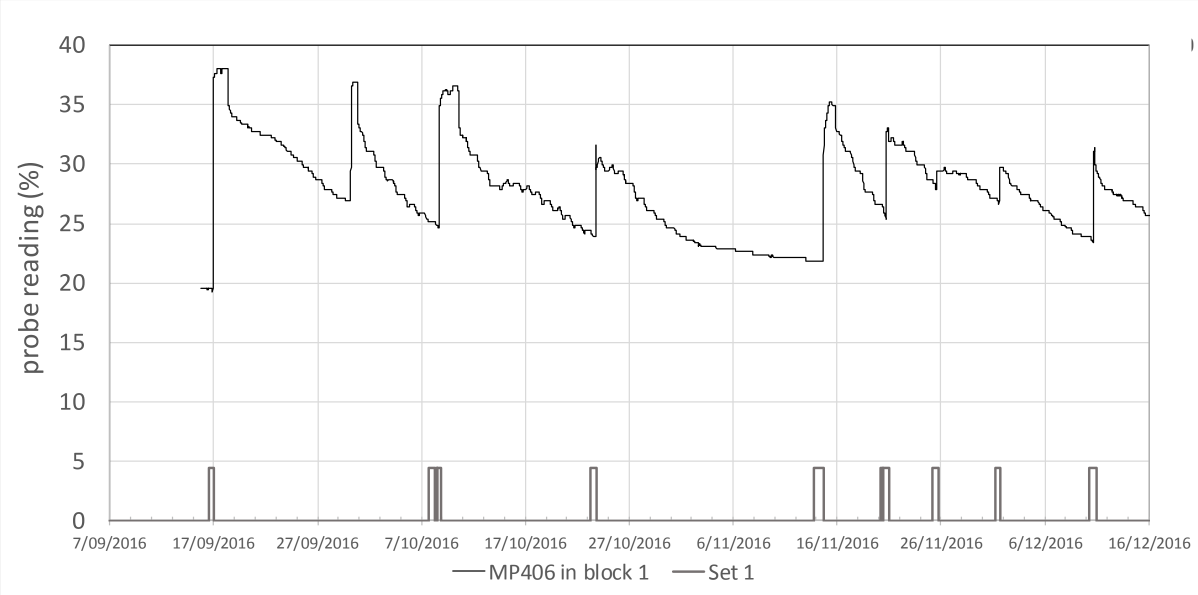


Figure 6-48 – Data from initial testing of MP406 probe in block 1.

6.5.6.4. Test D - MultiFurrow Probes

The common problem of all soil moisture probes is that they only measure a small volume of soil, and therefore each probe is only able to sample a single furrow out of the block (e.g. 80 in each block in this field). Secondly, the MP406 will only allow a single probe on each set of wires and each WiSA radio can only accommodate two sensors in its default configuration. Thirdly, the three probes tested, the 5TM, GS3 and MP406, are all high cost being between $450 - $650 per unit.

The project set out to identify, or develop, a solution that could connect multiple low-cost sensors to a single cable and to a single WiSA radio. The MODBUS protocol appeared to be a potential option as it allows connection of multiple (up to 255) devices to a single set of cables with two-way communication if required. MODBUS is common in the process control industries but not common in agriculture and there are limited probes available which can use communicate using this protocol. Therefore, one option is to transform the signal from an existing soil moisture sensor into the MODBUS protocol.

Two sensor options were investigated, the gypsum block and the low-cost voltage sensors. These sensors would be then connected to a board designed by the NCEA for this project which could transform the individual analogue sensor readings into a digital MODBUS communication standard. The board was designed such that it could be connected to 4 voltage/gypsum sensors; if additional sensors were required, other boards could be connected in series with the first. The standard WiSA boards do not include the ability to communicate through MODBUS and therefore a Modbus/RS485 expansion board was purchased which can be connected to any of the existing WiSA field radios. Each board has a unique address (0-255) which when queried will respond with the voltage on each of the 4 ports.

There are a range of different analogue voltage sensors available from the cheap $1.00 versions sold for electronics hobby kits to the more reliable Decagon and MP406 probes. Generally, each of these probes will transmit a voltage which is either linearly (MP406) or non-linearly (e.g. Decagon GS1) proportional to the soil moisture content. The sensors chosen for this trial were the Decagon GS1 probes which are similar to the GS3 probes in terms of design durability and accuracy but are between 1/3 to ½ of the price.

The final solution consists of:

- MODBUS expansion board inside the WiSA radio unit,
- Single (4 wire) cable connected to NCEA MODBUS node (inside the field),
- NCEA MODBUS node connected to up to four sensors (each on short length of cable),
- The MODBUS node can be connected in series to any further number of nodes each with up to four sensors.

Currently each WiSA radio is limited to 24 digital measurements per node (28 total minus 4 analogue) and therefore the theoretical limit is 24 soil moisture probes.

There were several issues in early testing and communication with the WiSA expansion board with some failed field tests in 2016. Most of this was due to the WiSA expansion board using a non-standard MODBUS communication scheme. With some minor software changes and successful testing in January 2017, one of these units was installed in block 3 at this site connected to four Decagon GS1 (analogue voltage) probes. The GS1 is approximately 1/3 of the cost of the GS3 but is still one of the most robust sensors available in terms of expected life in the field.

The Multifurrow sensors were deployed in Block 3 on the 27/01/2017 and functioned continuously until the 25/03/2017 when all WiSA nodes were removed from the field in the preparation for the potential cyclone which was originally predicted to impact the Burdekin. The data collected during this time is given in Figure 6-49. The sensors were installed at 26 m from the end of the field, 1259 m from the top end and at the same 150 mm below the ground surface in the irrigated furrow. The sensors were set to log on a 5 minute interval to enable detection of the precise time that the advance reached the 1259 m mark in each furrow.

Figure 6-49 shows that the probes are communicating properly with the WiSA system but there were some issues visible in this data. Probe number 3 gives a value close to 50% soil moisture continuously from the day of installation with minimal change due to irrigations or rainfall. A 50% soil moisture value indicates that the soil is close to field capacity and therefore it is no surprise that irrigations are not detected. On the 9/03/2017 this probe was excavated and it was confirmed that the soil was continuously at a high moisture content and probably too far away from the closest stool so that the soil did not dry out sufficiently between irrigations. It is worth stating that this part of block 3 has a soil which is somewhat different to that of the rest of the field. Here the soil appears to have a higher clay content and has poor drainage indicated by the motley soil colours. This probe was moved 2m and inserted into the side of the furrow against the stool and from this point onwards the soil moisture is more representative of the other probes.

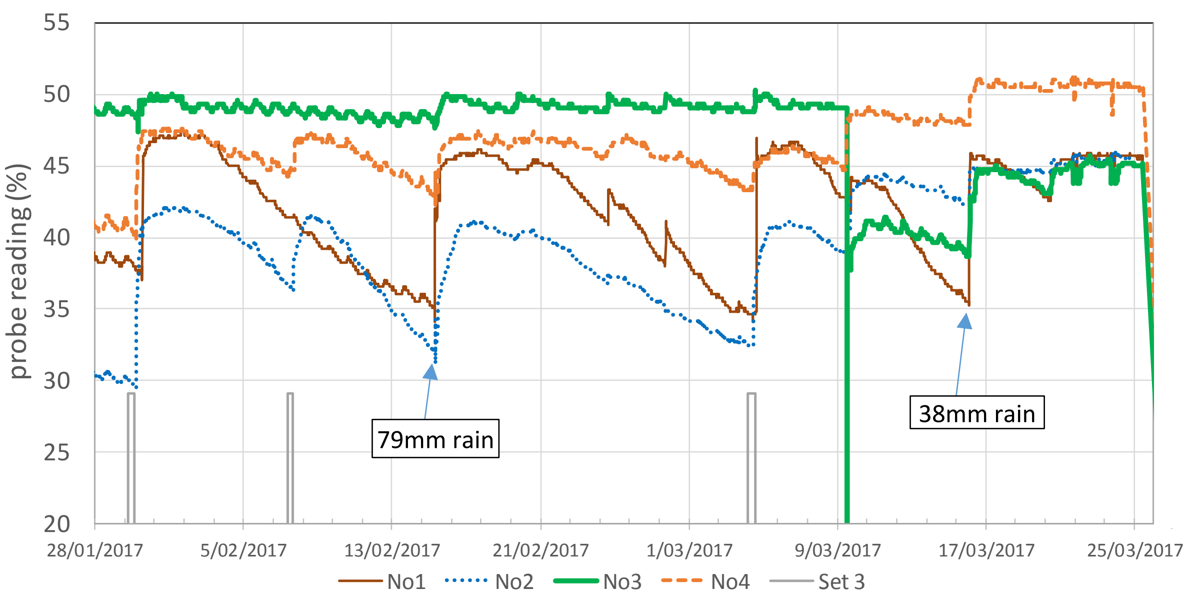


Figure 6-49 – Data from Multifurrow advance sensors.

Apart from this issue with the high moisture contents it appears that the sensors are able to detect the advance front and should be useful in measuring the furrow to furrow variability. Following the successful testing of the Multifurrow sensors they will be deployed in later 2017 in Block 1 as part of the Smarter Irrigation project.

6.5.6.5. Determining the Optimal Trigger Distance

The ultimate objective for this grower is to minimise tail water but strive for complete irrigation of as many furrows as possible. For this 1285 m long field, this requires switching to the next block some time before the water reaches the end of the field.

The behaviour of the system can be best understood by considering an example irrigation event. All furrows in the set are irrigated with the same flow, which commences at the same start time. Flows may vary slightly between furrows due to non-uniformity in the cups. Under manual measurement, the best the farmer can do is to wait for water to reach the end of the field and stop the irrigation event. It is impossible to see the progress of the water until it reaches the end because of the density of the crop. In reality, it is often difficult to tell if water is either pooled at the end of the furrow or is actually running off the field out of that furrow. More realistically, the grower will guess when the water might reach the end of the field and then come and check if the water has reached the end.

This means that the grower might either be too late and miss the water reaching the end or be too early and have to return the field for a second or third time, several hours later. Even if the completion time is known precisely, there is no guarantee that this will coincide with the optimal cut-off time. In some fields, the irrigation may need to continue for a set period after the water reaches the end, but for this field the optimal time will normally be several hours before water has reached the end.

The rate of water advance, the time the water takes to reach the end of the field, and the optimal irrigation time will vary between events depending on the soil characteristics at that time and the flow during the event. Previous work from in other industries (e.g. Uddin et al., 2014) has investigated the relationship between advance time to a point, and the optimal cut-off time; here instead the focus will be trying to identify a distance which corresponds to the optimal cut-off time.

It was proposed that SISCO modelling of the field would be able to determine the optimum cut-off time for a series of events. Then the model would be used to predict the location of the advancing front which corresponds to that optimal time. Placing the advance sensor at that position would greatly simplify the control logic and negate the requirement of having the model operate in real time for every irrigation. Basically, the aim would be to build in the SISCO optimisation process into that probe distance. At the very least, this position would provide the closest possible position of a control sensor to the end of the field.

In December 2016, all previous events on the 5 blocks were analysed to determine the optimal cut-off time and corresponding advance distance for that time. The results were collated and used to find the most appropriate distance for the sensor in that block, which would give good prediction of cut-off time for most events.

For example, Table 6-9 shows the irrigation events from block 3 which were used to determine the trigger distance for that block. In 2016, there were a total of 6 events with reliable advance data and inflow which could be used to run the SISCO simulation model. The time taken for water to reach the end of the field, in this block, ranged from 878 to 1427 minutes with a similar range in the farmer controlled irrigation times (actual duration). Note that all irrigations at this site since April 2016 have been controlled through the automation, but the irrigation schedule during 2016 was set manually by the grower. Applying a simple conservative optimisation strategy of 5% runoff, a range of cut-off times (TCO) distances were determined. The TCO distance is the position of the advance corresponding to the time of the optimal shutoff. Taking the mean of the first 5 events in the table (as the November event is the first event after harvest and is atypical) yields a trigger distance of 1132 metres or 153 metres from the tail end of the field. This was rounded to 150 m for simplicity.

Table 6-9 - Determining the trigger distance for block 3

Start	**Actual Duration** (min)	**Time to End** (min)	**Optimal TCO (5% runoff)** (min)	**Distance for TCO** (m)
8/04/2016 6:08	1404.3	934	800	1124
24/04/2016 6:52	975.2	887	770	1136
4/05/2016 8:01	842.1	878	760	1132
17/05/2016 10:25	844.3	947	830	1145
28/05/2016 16:14	853.1	864	740	1123
19/11/2016 5:18	1691.9	1427	1345	1221

A similar approach was used for the other blocks using the flow data and advance times from the end of row sensors. The final distances determined for each of the five blocks are given in Table 6-10 below. Block 3 tends to have a shorter trigger point distance because of a higher flow-rate than the other fields, and block 5 has a longer distance due to the fact that the soil infiltration rates are higher than the other blocks. In December 2016, MP406 soil moisture probes were installed at these optimal trigger distances and wired into the WiSA nodes at the tail end of the field. In this case, the wires from each probe travel straight to the end of the field along the row and then across the end of the field in the tail drain.

Table 6-10 – Trigger distances (rounded for ease of installation) for the Demo Field.

Irrigation set	Distance from end (m)	Distance from top (m)
1	100	1185
2	100	1185
3	150	1135
4	100	1185
5	85	1200

After Russell gained confidence in the relationship of these sensors to the correct cut-off time, he then altered the irrigation program such that it would switch to the next set at the time that the probe was triggered. Figure 6-50 shows two example irrigations in sets 2, 3, and 5 while Russell was using the probes to automatically stop the irrigations. In both cases, the program was set to irrigate set 2, switch to set 3 when the probe (T2) was triggered, and then stop the irrigation when the set 3 probe (T3) was reached. In both cases, the water would have reached the end of the field 1 to 2 hours after the set was stopped. This can be confirmed by considering the Multifurrow probes in set 3 which are positioned at 1259 m (26m from end) compared to the trigger sensor at 1135 m, two examples are as follows:

- 29/01/2017 – trigger at 541 min., valve closed at 541 min., Multifurrow at 621 minutes
- 7/02/2017 – trigger at 429 min., valve closed at 429 min., Multifurrow at 489 minutes

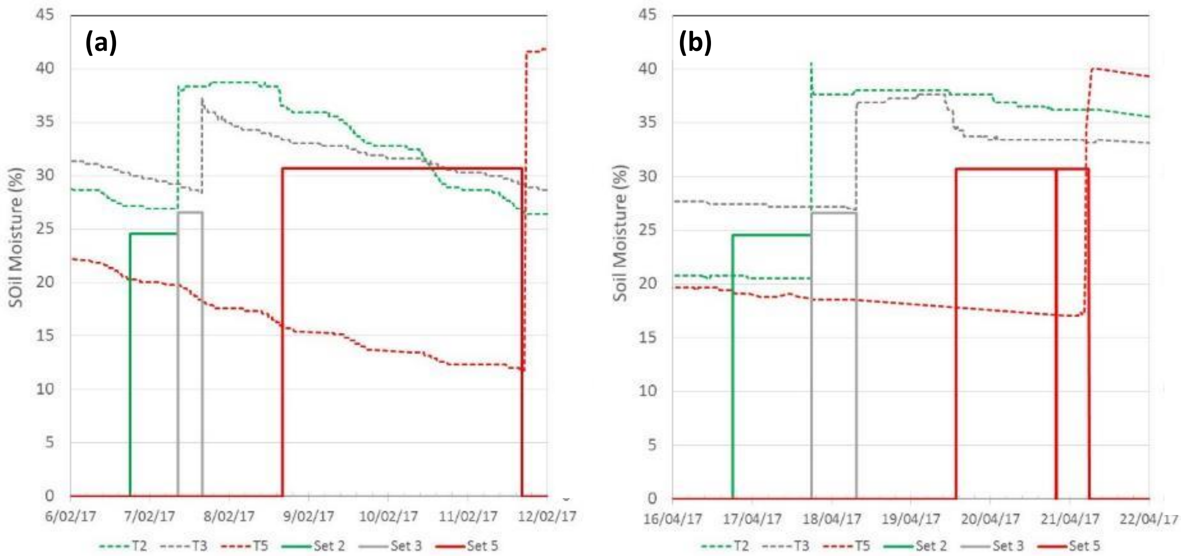


Figure 6-50 – Example irrigations after installation of optimal trigger distance probes.

Set 5 was proving difficult to irrigate in these two examples, as it was taking a long time for water to reach the end of the field. On both cases Russell kept close watch on the progress in Set 5 using sensors and visiting the field (as he at first thought that the Set 5 probe was malfunctioning) and stopped the irrigation at the optimal time. While Set 5, in this case, is an extreme event, the contrast between the three irrigation run times is a good illustration of the potential variation in optimal shut-off times between different blocks in the same field, each with similar inflows, the same field length and similar number of drills per set.

6.5.6.6. Final advance trigger positioning

After successful testing of the optimal trigger distances and MP406 probes, Russell Jordan was now prepared to trench the sensors and cables permanently into the ground. The earliest this could be attempted was August 2017, just after the sugarcane was harvested from these blocks. This trenching was the initial plan for these infield sensors so that all infield operations, such as light cultivation, planting, fertilising, spraying and harvesting can be carried out with the sensors remaining safe within the field. The sensor is still located at the same depth underneath the furrow, but the cable from the WiSA node to the sensor is now buried at a depth greater than 500 mm and protected within PVC rigid walled electrical conduit (Figure 6-51 a). A cultivation disc is buried underneath the probe (Figure 6-51 b) so that the probe can be located with a metal detector, if it needs to be replaced in the future. The precise location of the probe is also recorded using the tractor GPS so that Russell can avoid this location if he does choose to conduct any deep ripping in the future.

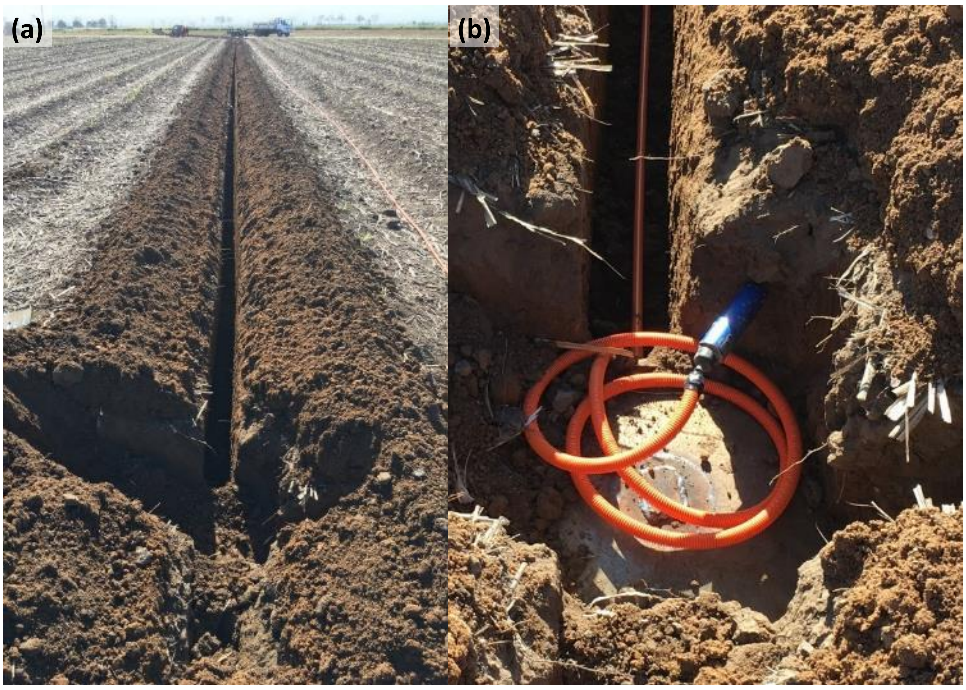


Figure 6-51 – Permanent installation of advance probe (a) trench to end of field and (b) MP406 probe being installed above cultivation disc with spare cable.

7. SPECIFICATIONS OF DEVICES USED WITHIN THE TRIAL SITES

7.1. Introduction

One of the aims of this project was to establish the range of components which would be suitable for practical use in an on-farm automation system for furrow irrigated sugarcane. Throughout the project various devices were investigated, a portion of these were tested and a subset of these were then used in the final systems currently deployed at the three demonstration sites. This section will provide technical specifications for these components.

7.2. WiSA Nodes

7.2.1. WiSA Node Specifications

WiSA produces a range of different field nodes, but all control and end of field detection nodes, in this project, were the Hybrid Board Version 3.1. This board is termed a hybrid because it accommodates a number of inputs and outputs compared to other configurations which may have a larger number of outputs but fewer or no inputs. This hybrid board has the following ports as shown in Figure 7-1:

- Battery power (12 V)
- Solar power port (12 V solar panel input)
- 4 analogue input ports which may be configured for:
    - 4-20 mA
    - Pulse counter (i.e. flowmeter, rain gauge)
    - Switch
- 1 Digital (SDI12) port
- Optional Modbus/RS485 module (replaces SDI12 port)
- 4 output ports to switch solenoids or actuate valves

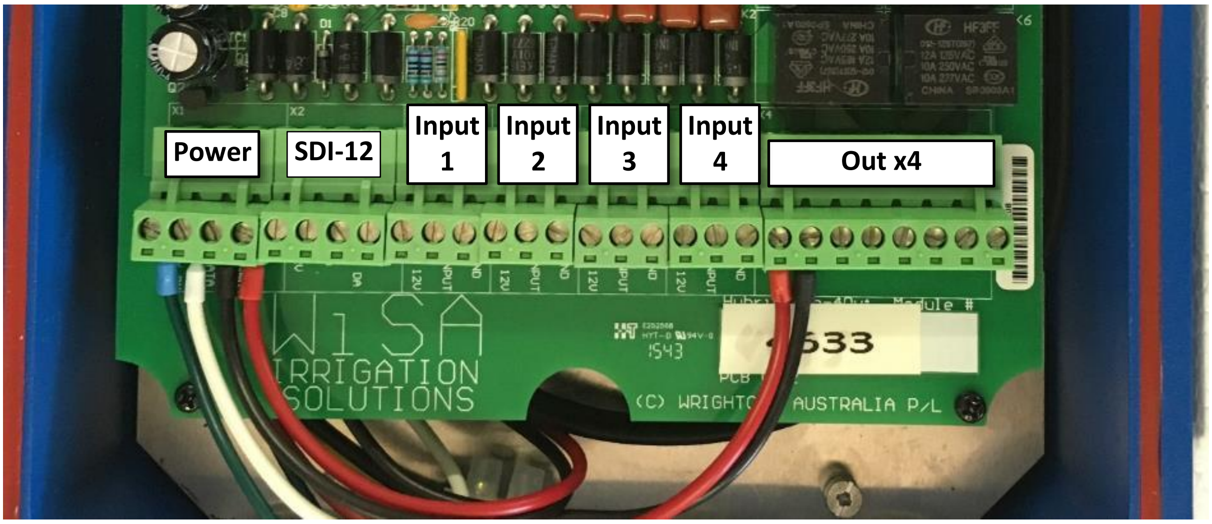


Figure 7-1 – Ports on the WiSA Hybrid Board

The 4 analogue inputs are made up of a 12 V constant supply, signal wire and common ground. These inputs can be configured at any time to connect to devices such as pressure sensors (4-20 mA), flow switches (switch), flowmeters (pulse) or rain gauges, (pulse). In the case of a pulse flowmeter a resistor may be required across the 12 V input in order to reduce the voltage to a suitable level for the pulse device.

The digital port is configured for connection of SDI-12 sensors which is commonly used by soil moisture sensors. Typically, SDI-12 devices can be assigned addresses 0-9 which means up to 10 separate probes, some devices are capable of operating at higher address numbers which means that more than 10 sensors could be connected to this single port. Sensors which have been connected to the WiSA nodes during this project include Decagon 5TM, Decagon GS3, MP406, Enviropro capacitance and Aquaspy capacitance soil moisture sensors and the Unidata Starflow flowmeter.

Connection of the optional Modbus expansion board enables the WiSA node to connect to a range of Modbus and RS485 sensors.

The 4 output ports provide the opportunity to switch 12 V outputs, and are currently utilised to control the actuators. The actuators are controlled by reversing the polarity of the output ports.

7.2.2. Radio Communications

The WiSA automation system relies on radio communication between each field node and a base station connected to a personal computer. The units operate around the 900 Mhz frequency with recommended range of approximately 5 km line of sight. In all three demonstration sites, the antenna was simply located on the top of the roof of the house or shed where the base station PC is located.

There were no issues in radio communications at the Pozzebon site or Linton site, because in those cases none of the nodes were situated any further than 3 km line of site from the base station. The WiSA nodes at the Jordan site are located up to 6.5 km away from the base station and had some difficulty in reliably communicating with the base station. The direct path passes through sugar fields and four separate sections of trees which are higher than the antennas. This meant that radio communication to the control valve was intermittent and unreliable. The radio network is not self-meshing like that of its competitors but the default communication path can be set for each radio node. Hence all of the radio nodes were configured to route the signals through the Cadio Road pump station module, which is 4.3 km from the furthest part of the Demonstration Site, and only 3.5 km from the base station, as shown in Figure 7-2. Part way through the season, the end of row sensor node for block 5&6 started to have communication drop-outs so it was reconfigured to communicate to the end of field radio for blocks 1&2, then Cadio Road and back to base station. The process of setting the radio paths is a simple task performed on the computer connected to the base station which can be done remotely through software such as TeamViewer.

The field nodes were originally mounted on 2 m aluminium poles but this was later upgraded to 3m masts in some locations to raise the height of the antenna above the sugarcane canopy. For two of the Jordan nodes these poles were lifted even higher by mounting the poles to the top of the concrete cylinder risers.

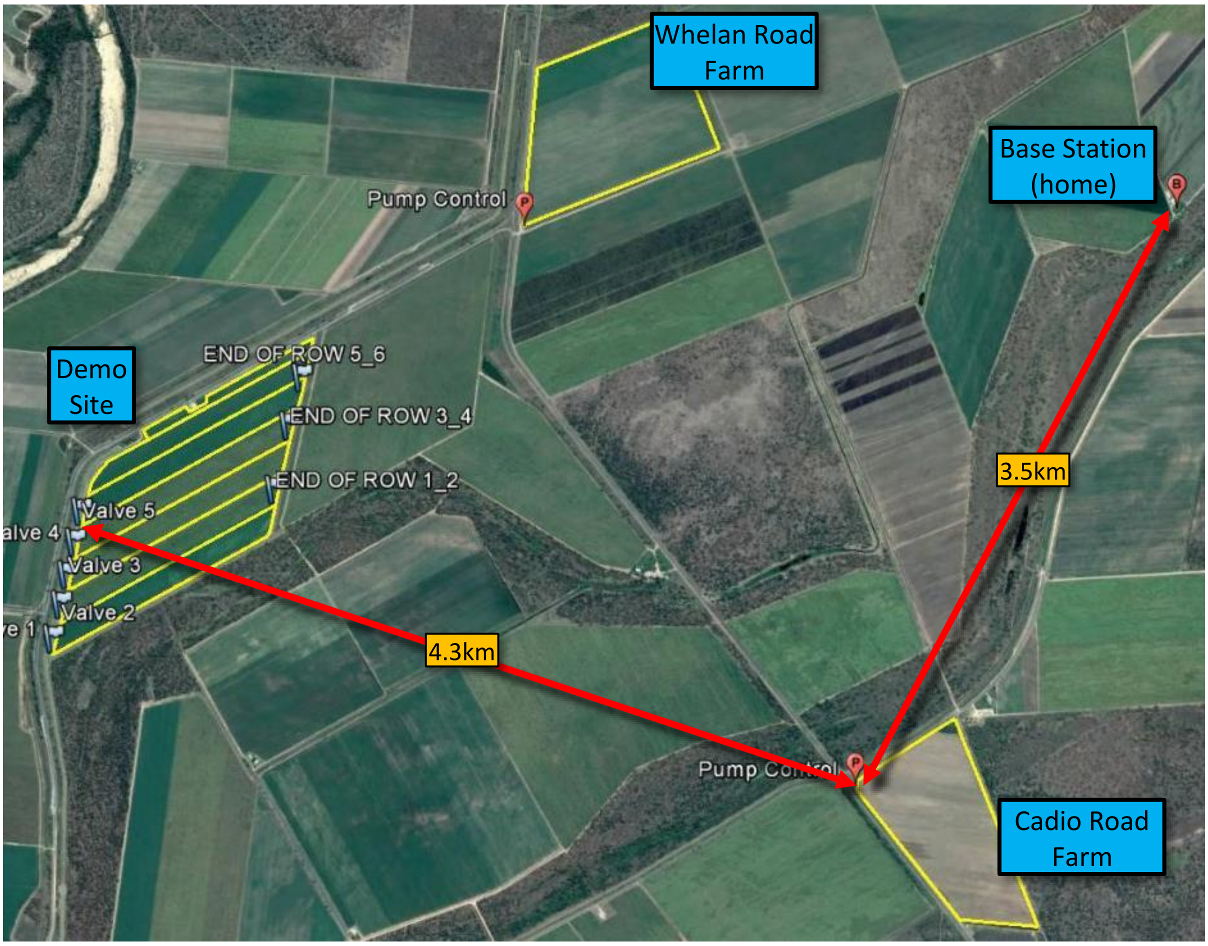


Figure 7-2 – Position of the Demonstration Site relative to the base station (Google Maps, 2017).

7.3. WiSA Software

The radio base station is connected to a personal computer running five different pieces of software for various tasks relating to the automation system:

- **AquaLink –** The main control software, to monitor and control the system
- **Site Config –** Ability to configure all aspects of the server side of the automation system
- **GroGraph –** The user can design a number of graphs to display the data collected by the system
- **WiSA Configurator** – Ability to configure each radio node remotely
- **WiSA Diagnosis Tool**– Ability to configure each radio node remotely

The project team accessed these tools remotely using TeamViewer.

7.3.1. AquaLink

AquaLink is the PC based software for interfacing with the WiSA automation system. AquaLink allows the user to monitor, control and schedule the irrigations. As shown in Figure 7-3, the main screen is set up with a schematic and icons for each device are positioned accordingly on the appropriate blocks. The Demonstration site is the “Black Road” farm on the upper right side of the screen. The other two farms in this screen are only instrumented with a pump controller.

Figure 7-3 – AquaLink main control portal for Russell Jordan's farm.

AquaLink allows the user to set up an irrigation schedule with a combination of time based and trigger based timings. The user can also configure the protection system which is comprised of a series of actions that will be performed or SMS messages corresponding to predefined sensor values. For example, an alarm can be set to send an SMS to the grower if the battery level in one of the nodes gets too low, or the entire system can be set to shut down if the pressure rises above a set value. Operation of the alarm and scheduling systems requires the software to be running and for the irrigation timer and protection system to be active. For this reason, the computer has been configured to automatically start this software on Windows Start-up, so that the system can recover itself if there is a power outage at the base station.

7.3.2. Site Config

Site Config is the software which can be used to configure and customise the way in which AquaLink functions. Each of the field node radios is simply sending and receiving data but it is the task of AquaLink to make sense of this data and log it at the appropriate interval. For example, each of the radio nodes can send up to 28, 16 bit integers. A 16-bit integer is a value ranging from 1 to 65,536. The Site Config allows the user to define where AquaLink can find each piece of information, i.e. the node number and the address and then how and how to convert that 16-bit integer into a meaningful piece of information. A simple example of this conversion is given below:

i) Soil moisture sensor reports a volumetric soil moisture of 32%
ii) The WiSA node has been configured to expect a number between 0 – 100% and therefore converts this into a 16-bit integer by using 32/100 x 65,535 = 20,971
iii) The value of 20,971 is received by the base station and AquaLink has been configured to convert this integer into a value ranging from 0-100% therefore the resulting value would be 32.0%

A similar configuration is performed for each sensor connected to the WiSA nodes. Typically, use of this software is limited to first time set up of a new sensor or control device and the farmer typically has no need to operate this tool. WiSA have produced a setup manual which guides the user through most of the important parts of this software.

7.3.3. GroGraph

Every action and reading detected by the automation system is stored in a database housed on the PC. GroGraph is the software which can transform this data into useful information in the form of graphs and reports. The user can create a graph using any of the stored data elements, the example shown in Figure 7-4 contains the block run times, pipeline pressure and flow measured by the furrow flowmeters which were present in the system for the first half of 2016. GroGraph also serves as the tool to extract data from the database for external analysis. The user can choose to export a CSV text file from the system containing the data visible in the graph.

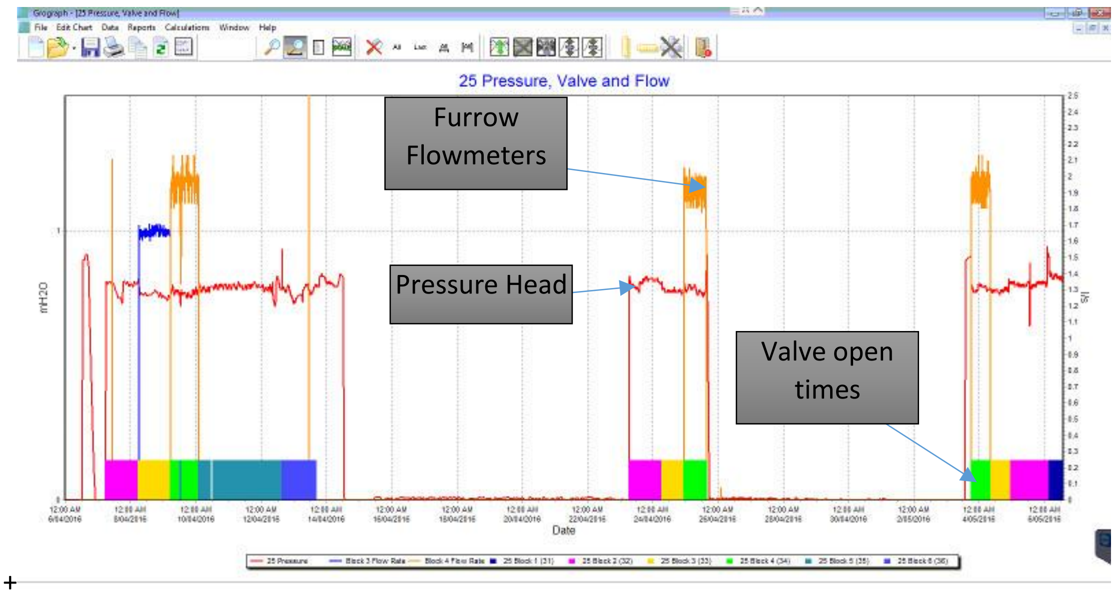


Figure 7-4 – Example plot from GroGraph.

7.3.4. WiSA Configurator and Diagnosis Tool

There are two small pieces of software which can be used to configure and test the boards on the remote field radio nodes. Both tools require that AquaLink is closed so they can take control over the radio base station. These tools are not designed for farmer use but instead be used throughout the installation and commissioning of the WiSA nodes and their associated devices.

The configurator tool is used to define what is connected to each one of the ports on the module board as shown in Figure 7-1. Here the user also defines which pieces of data are sent back to the base station from the various sensors connected to the device and the corresponding position of each data element in the 28 available registers.

The WiSA Diagnostics tool is for sending commands to an individual node in order to test that everything is working properly. This tool is useful because it is otherwise difficult to see the raw values returned from each node though the AquaLink software.

7.4. Supply Sensors

7.4.1. Pressure sensors

Pressure sensors are an essential part of the system to diagnose problems, and reassure the grower that the pumps and valves are working properly. Both flowmeters and pressure sensors monitor the supply system, but pressure sensors are far more sensitive to changes in the system and are less expensive and easier to install than most flowmeters. A range of different devices were used across the sites as described in the previous chapter. Below is a list of these devices and the corresponding specifications:

Trafag 8473 ECT0.4A & ECT0.6A

Type: Non-Submersible PST
Signal: 4-20 mA, 2 wire
Reading: 0 – 0.4 bar (0 - 4.08m), <0.5% (<20mm) accuracy.
0 – 0.6 bar (0 – 6.12m), <0.3% (<18mm)
Options: available in 0.1, 0.16, 0.2, 0.4, 0.6, 1.0, 1.6, 2.5, 4, 6, 10 bar models.
Notes: sensor will be damaged if exposed to >20.4 m head.
Connection: Input port, white to 12 V, brown to signal

Trafag 8438 ECL0.2A & ECL0.4A

Type: Submersible PST
Signal: 4-20 mA, 2 wire
Reading: 0 – 0.2 bar (0 - 2.04m), <0.5% (<10mm) accuracy.
0 – 0.4 bar (0 - 4.08m), <0.5% (<20mm) accuracy.
Options: available in 0.1, 0.2, 0.4, 0.6, 1.0, 1.6, 2.5, 4, 6, 10 bar models. Optional 0.3% accuracy
Notes: sensor will be damaged if exposed to >12.2 m head.
Connection: Input port, white to 12 V, brown to signal

Wika LS-10

Type: Submersible PST
Signal: 4-20 mA, 2 wire
Reading: 0 – 0.25 bar (0-2.55m), <0.5% (<12.5mm) accuracy, <0.1% (2.6mm) non-repeatability
Options: Available in 0.25, 0.4, 0.5, 1.0, 1.6, 2.5, 4 & 6 bar models. Optional 0.3% accuracy
Connection: Input port, red to 12 V, black to signal

Wika S-10

Type: Non-Submersible PST
Signal: 4-20 mA, 2 wire
Reading: 0 – 0.25 bar (0-2.55m), <0.5% (<12.5mm) accuracy, <0.1% (2.6mm) non-repeatability
Options: Available in 0.1, 0.16, 0.25, 0.4, 0.6, 1.0 & 1.6 bar models. Optional 0.25% accuracy
Notes: sensor will be damaged if exposed to >20.4 m head.
Connection: Input port, red to 12 V, black to signal

The fact that several different probes have been tested indicates that the WiSA system should be able to accommodate any PST which operates on 12V and relies on 4-20 mA to transmit the signal.

7.4.2. Flowmeters

Flowmeters may also serve as a means to determine if the system is working as intended but for this project they enabled measurement of water use and partitioning of that use into individual blocks. Most modern flowmeters provide an optional pulse output which is compatible with the WiSA node analogue inputs. Flowmeter pulse outputs will register a pulse at a predefined number of Litres (e.g. 10, 100 or 1000 L). The specifications of the flowmeters used are as follows:

Siemens Sitrans MAG 8000 (both 250 mm and 200 mm models) – For pump flowrate

Type: Electromagnetic meter
Signal: 10,000 L pulse (default), reconfigured to 100 L pulse
Reading: Cumulative kL on device, 0.4% accuracy (optional 0.2%), accurate to within 0.2 L/s
Notes: No power required, meter contains battery.
Connection: 510 Ω resistor between signal and ground on WiSA, +ve from meter to SDI12, +5 V & -ve from meter to signal on WiSA. (this is just one possible way of connecting)

Elster Q4000 (both 80 mm and 100 mm models) – For individual furrow flows

Type: Electromagnetic meter
Signal: 10 pulse (default)
Reading: Cumulative kL & m^3/hr on device
Notes: No power required, meter contains battery.
Connection: 510 Ω resistor between signal and SDI12 +5 V on WiSA, +ve from meter to signal & -ve from meter to ground on WiSA.

Unidata STARFLOW

Type: Doppler flowmeter
Signal: 10 pulse (default)
Reading: Water velocity, pressure, temperature, battery voltage through SDI12
Notes: Normally is used as a logger but can be reconfigured as a SDI-12 sensor
Connection: SDI-12 to WiSA port, 10K Ω resistor between serial (Starflow) and 12 V on WiSA.

7.4.3. Drainage and Advance Sensors

A number of different sensors were tested for potential use as advance or drain sensors. Four different connection types were tested; SDI-12, 4-20 mA, Modbus and voltage.

SDI-12 is a digital protocol, and therefore can return several different values from each sensor and have multiple sensors attached to a single set of wires. Each WiSA node can connect to >10 SDI-12 sensors through a single port. Recommended max cable length between node and sensor is 70 m, during the project lengths of up to 400 m were tested but caused unreliable readings. SDI-12 sensors are very common but are of mid to high cost.

4-20 mA is an analogue protocol which is commonly used by PST sensors and therefore accommodated by the WiSA node. Here, the current through the sensor varies according to the soil moisture value. Each WiSA node can connect to up to 4 of these sensors, each with independent sets of wires. The main benefit of 4-20 mA is that cable lengths between sensor and WiSA node can be much greater than for SDI-12 sensors or voltage sensors. There are limited 4-20 mA sensors available and the one identified is the highest cost sensor of all tested.

ModBus/RS485 is another example of a digital protocol which is commonly used in process engineering but less commonly used in modern soil moisture sensors. Modbus sensors can theoretically function with greater lengths of wire between sensor and node than SDI-12 sensors.

Voltage sensors are another example of an analogue sensor but this time the voltage changes with the soil moisture. These sensors range from being very inexpensive and inaccurate to some of the most accurate sensors available. WiSA nodes do not accommodate voltage sensors but the project team was able to develop a unit which can translate voltage readings into a Modbus signal. Some of the notable examples are:

Decagon 5TM soil moisture – Used as both drain level (in air) and buried advance (in soil) sensor

Type: Capacitance soil moisture
Signal: SDI-12
Reading: 2 values = dielectric permittivity + temperature
Notes: Soil moisture calculated from permittivity (SM 0 to 100%)
Connection: SDI-12 port on WiSA node (white=12 V, red=data, bare=ground)

Decagon GS3 soil moisture – Used as both drain level (in air) and buried advance (in soil) sensor

Type: Capacitance soil moisture
Signal: SDI-12
Reading: 3 values = dielectric permittivity + temperature + EC
Notes: Soil moisture calculated from permittivity (SM 0 to 100%)
Connection: SDI-12 port on WiSA node (12 V=white, Red=data, bare=ground)

ICT MP406 mA version – Used as both drain level (in air) and buried advance (in soil) sensor

Type: Capacitance soil moisture
Signal: 4-20 mA
Reading: Soil moisture calculated from signal using equation
Connection: WiSA analogue port set to 4-20 mA, +12 V, input and ground of sensor to corresponding WiSA pins.

Decagon GS1 soil moisture – Used as buried advance (in soil) sensor

Type: Capacitance soil moisture
Signal: voltage (1,000 mV to 2,500 mV)
Reading: voltage converted to SM using equation
Notes: Soil Moisture (SM 0 to 57%)
Connection: Connected to Device built by NCEA

NCEA Modbus unit – Prototype developed during project.

Type: Connects to voltage sensors or gypsum blocks
Signal: Modbus
Reading: sends 4 numbers, one for each sensor
Notes: Each unit connects to 4 sensors; several units can be connected in series to a single set of wires back to the WiSA node.
Connection: WiSA Modbus expansion board

Acclima TDR315L soil moisture – Deployed as buried SM sensor

Type: Time domain reflectometry (more accurate than capacitance)
Signal: SDI-12
Reading: 5 values = Soil moisture content + temp + permittivity + bulk EC + pore water EC
Notes: Soil moisture range of 0 to 100%.
Connection: SDI-12 port on WiSA node (red=12 V, blue=data, white=ground)

7.4.4. Other Devices

LINAK LA35 300mm – For actuation of butterfly valves.

Type: linear actuator
Signal: 12 V supply, polarity reversed for changing direction
Notes: Also available in Modbus version for position control (not tested in project)
Specification: 6000 N push and 4000 N pull for tested model.
Connection: Connected to output ports (1 per actuator)

Davis Rain Collector (tipping bucket rain gauge)

Type: Tipping bucket rain gauge
Signal: switch closes on every 0.2 mm of rain
Notes: This test confirms that WiSA node will handle any standard tipping bucket rain gauge
Connection: analogue input port configured to pulse, 1 wire to ground, 1 wire to input.

Kelco F25 flow switch

Type: paddle flow switch
Signal: switch closes when flow pushes paddle downstream
Notes: These sensors are commonly used to protect pumps
Connection: analogue input configured to switch, 1 wire to ground, 1 wire to input.

8. FIELD RESULTS

8.1. Pozzebon

8.1.1. Inflow and Head data

Limited analysis can be performed at the Pozzebon site because of the absence of flow data. There have been a total of 130 irrigation events controlled by the automation system as of 01/09/2017 with between 16 and 22 events per block on the initial 6 blocks. A summary of the data is given in Table 8-1 and a plot of the valve opening times is given in Figure 8-1 to Figure 8-4.

Table 8-1 – Irrigations since automation was installed at Pozzebon site.

Block	1	2	3	4	5	6	7	8
No. irrigations since automation	22	22	17	17	16	19	11	5
Average Head (m)	1.077	1.076	0.892	0.780	0.320	0.048	0.179	0.339
Std Dev Head (m)	0.142	0.190	0.084	0.091	0.061	0.065	0.220	0.051

Each head value given in this table is the water level in the cylinder located at block 5, both the average head and standard deviation of head between events are shown. As discussed earlier and presented in Figure 6-10, each valve operates at a nominal head value. The valves for blocks 1 and 2 are furthest away from the pump and therefore require more head to overcome friction losses. Blocks 6, 7 and 8 operate at a much lower head which in some cases declines to zero. This suggest that an additional pressure transducer is required closer to the pump to be properly able to monitor the system head for these most recently automated blocks. In addition to the reduced friction head, it is likely that the valves for blocks 6, 7 and 8 are lower in elevation than the position of the pressure transducer.

The standard deviation gives some indication of the variability of the head and therefore range of furrow flowrates. While they are relatively consistent, some blocks have experienced a range of heads, which would translate into flowrate variation between events. For example, block 1 has a mean of 1.077 m but the head has ranged between 0.754 m to 1.244 m across the 23 events monitored. This variation is probably a result of the complexity of the supply system with multiple pumps and potentially multiple irrigation sets running simultaneously. The flowrate is generally proportional to the square root of the change in head and therefore this range in heads would result in a similar but smaller range in flows for each block. The variation of flow, from event to event, will serve to make it impossible to predict the time the water will take to reach the end of the field, meaning that an irrigation schedule based on fixed times will not be satisfactory. This is where the value of the end of row sensors or drainage sensors becomes apparent, the irrigation can be stopped early if the water advance is faster than anticipated.

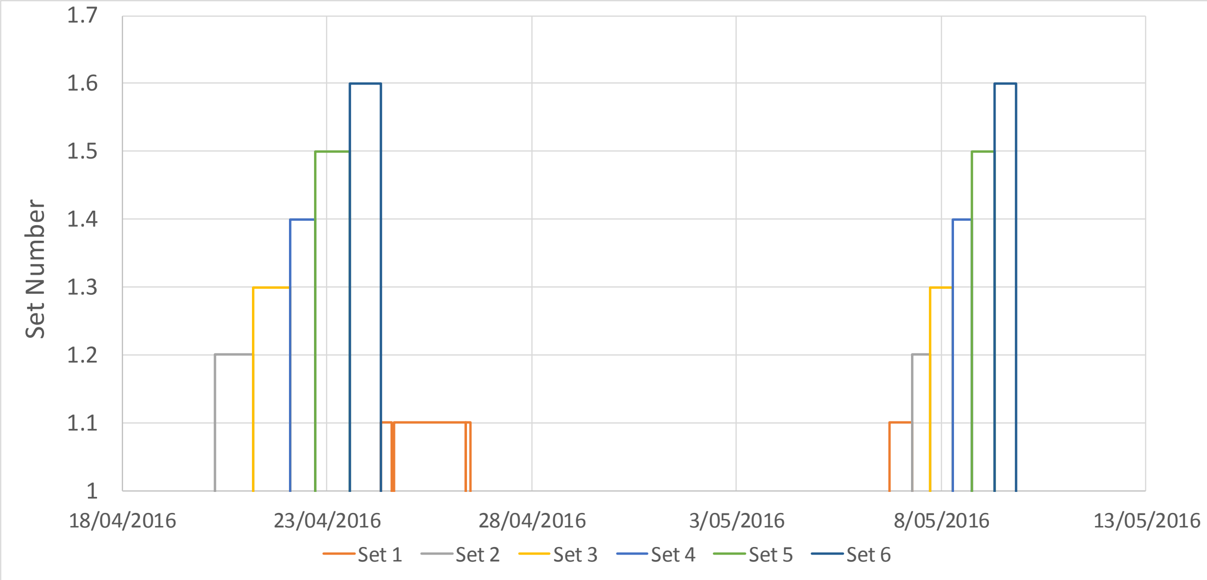


Figure 8-1 – Plot of valve opening times at Pozzebon Site for May - August 2016.

Figure 8-1 shows the two rounds of irrigations which occurred between installing the automation and harvest. The following three figures, Figure 8-2 to Figure 8-4, show all the irrigations which have occurred up until the 01/09/2017.

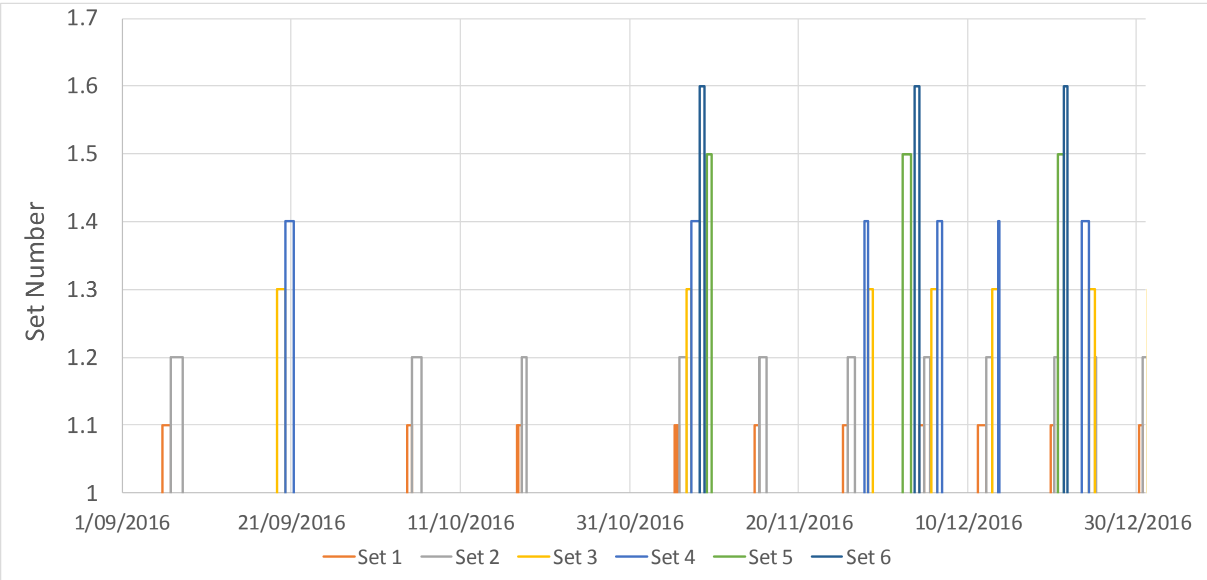


Figure 8-2 – Plot of valve opening times at Pozzebon Site for September 2016 - December 2016.

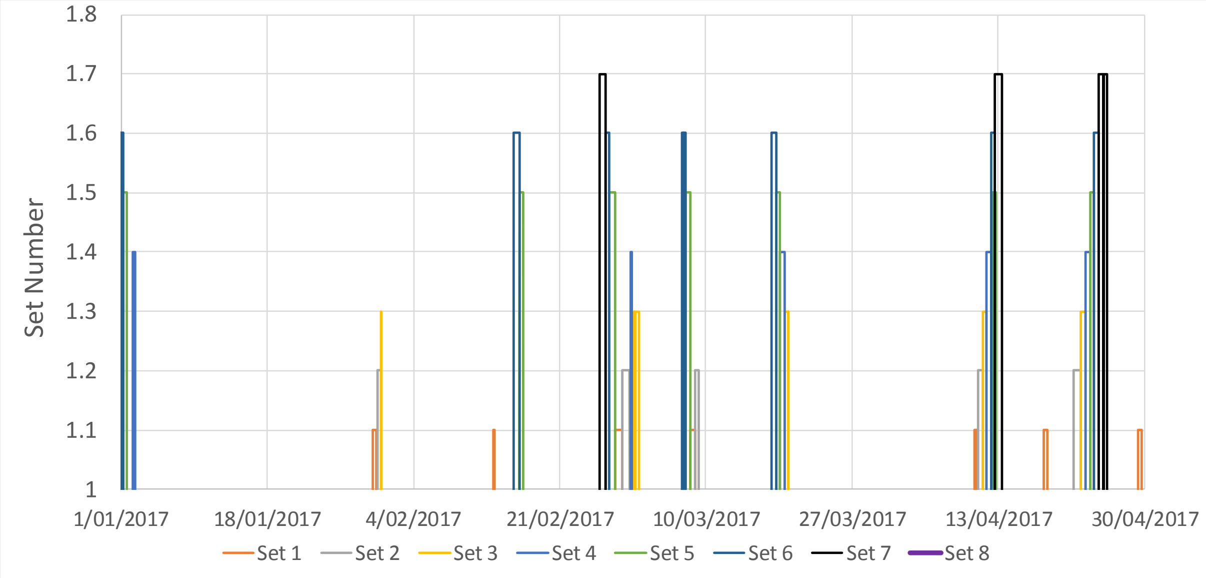


Figure 8-3 – Plot of valve opening times at Pozzebon Site for January 2017 – April 2017.

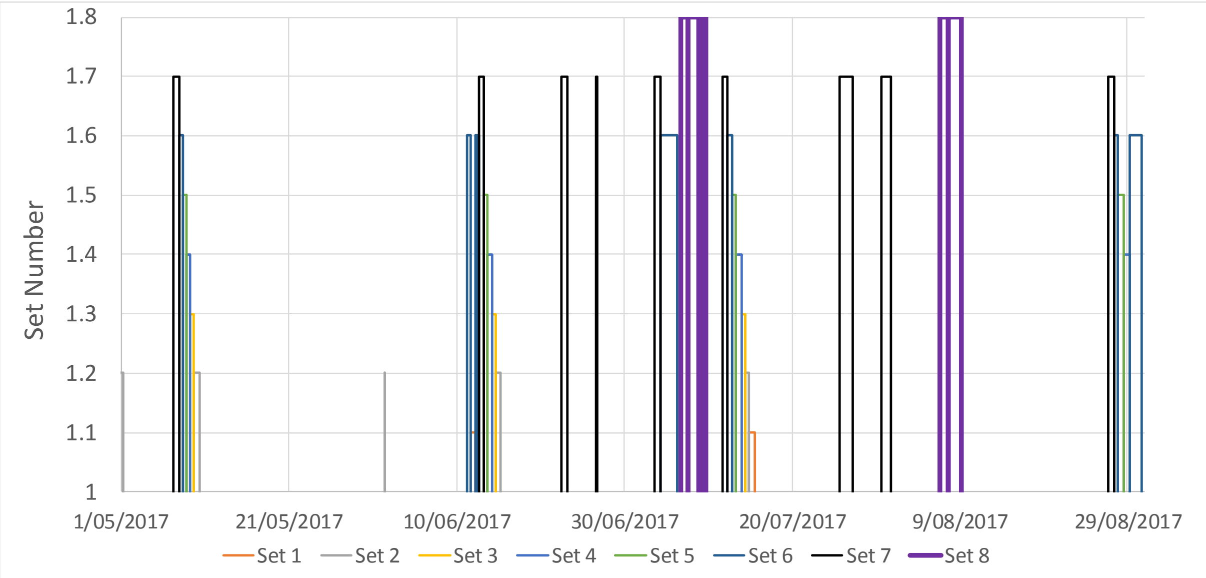


Figure 8-4 – Plot of valve opening times at Pozzebon Site for May 2017 – August 2017.

8.1.2. End of Field Drain Probe Data

The runoff from all 8 blocks can be collected using the on farm tail water recovery system and therefore runoff is not lost. This also means that Denis does not need to shut the inflow immediately when runoff commences. Table 8-2 provides a summary of the quantity of events where end of row times are available.

Across blocks 1- 6 there have been a total of 80 irrigation events since the installation of drain probes. Runoff was detected successfully for 3/4 of these events (61 events). While it might be concerning that 19 events are missing runoff, for many of these cases the inflow time was shorter than average and may have failed to reach the end. For block 7, only 5 out of the 11 events have runoff times, but this is a result of the radio node connected to this probe being disconnected between the 20/06/2017 and 25/08/2017 thereby missing 6 events.

Table 8-2 – Summary of drain probe data at Pozzebon site

Block	1	2	3	4	5	6	7
No. of irrigations since drain probe installed	17	9	14	14	14	12	11
No. with runoff detected	12	6	12	12	12	7	5

Block 4 will be chosen to illustrate the data available. For block 4 there have been 14 events since the installation of the drainage probe (Table 8-3), with runoff detected at 12d. Across these events the time of cut-off (TCO) ranged from 232 to 1406 minutes, the shortest event (13/12/2016) was probably so short that the water did not reach the end of the field. On the event of the 23/04/2017 the drain was already full and therefore the start of runoff could not be detected.

Table 8-3 – Summary of drain probe data at Pozzebon site for block 4.

Date	TCO		Runoff detected	
	(minutes)	(hrs)	(minutes)	(hrs)
7/11/2016 6:58	1406	23.4	295	4.9
27/11/2016 18:34	705	11.8	353	5.9
6/12/2016 9:39	930	15.5	308	5.1
13/12/2016 13:20	232	3.9	Shut off too early	
23/12/2016 11:24	1234	20.6	394	6.6
2/01/2017 7:43	452	7.5	269	4.5
1/03/2017 5:00	365	6.1	405	6.8
18/03/2017 16:50	759	12.6	277	4.6
11/04/2017 15:29	874	14.6	398	6.6
23/04/2017 4:54	713	11.9	Drain already full	
8/05/2017 17:55	718	12.0	392	6.5
13/06/2017 15:27	886	14.8	385	6.4
13/07/2017 7:59	923	15.4	423	7.0
28/08/2017 15:03	882	14.7	669	11.2

Considering the 12 events with runoff data, the average cut-off time (TCO) is 14 hours and the start of runoff occurs at an average 6.3 hours. The runoff detection time ranges from 4.6 hours up to 11.2 hours. The speed of advance is determined by the inflow rate and soil infiltration and therefore assuming that inflow rate is constant is an indication of the magnitude of infiltration. The wide spread of advance times also suggests that the cut off time should be altered between events to achieve optimal performance. Denis is not concerned about runoff losses but he has indicated that he may make use of the drain probe times to aid in irrigation management into the future.

8.2. Linton Site

8.2.1. Inflow and Head data

There have been a total of 410 individual irrigation events across the 11 blocks at this demonstration site up until the end of June 2017. This does not include short open times where the valve was opened for test purposes. A summary of the average flows and heads across the eleven automated blocks is given below in Table 8-4. Unlike the Pozzebon site, the flow and head for each block does not change significantly between irrigations. It is possible to pick which valve is open merely from knowing what the pressure head is. Valve 5 is closest to the pump and operates at the lowest head of 0.31 m, valves 11 and 12 are located on a cylinder which is furthest from the pump. Valves 3 and 4 are similar because they have a similar number of cups and are located at the same riser. Similarly, 6 is almost equal to 7 and 8 is almost equal to 9.

Table 8-4 – Flows and heads for Linton Site (as of 1/07/2017)

Block	No. Events	Flow (L/s)			Furrow flow (L/s)	Head (m)		
		Average	Min	Max		Average	Min	Max
1	17	76.1	73.2	77.3	1.02	0.68	0.62	0.70
2	43	75.0	68.9	76.9	0.65	0.88	0.76	1.03
3	74	62.7	59.3	64.8	1.45	0.62	0.34	0.81
4	70	62.1	58.3	65.3	1.41	0.73	0.65	0.79
5	33	63.0	60.6	66.7	1.09	0.31	0.27	0.40
6	44	58.2	55.4	60.2	1.13	2.08	2.03	2.12
7	36	58.3	55.5	60.3	1.05	2.16	2.14	2.18
8	32	55.2	53.4	57.3	0.98	3.24	3.20	3.27
9	42	55.4	53.6	57.7	0.94	3.12	2.92	3.36
10	20	55.6	53.6	56.4	1.46	3.46	3.42	3.58
11	16	54.0	52.1	56.1	0.68	3.51	3.37	3.64

Pump 1 has a higher flow than pump 2 but blocks 1 and 2 supplied by that pump have a larger number of cups. As a result, the flow per furrow is of similar magnitude across most of the blocks. For pump 2, block 5 has the highest flow as it is closest to the pump and the flow declines with distance away from this point, which was expected due to the increase in friction loss and headland elevation.

The following plots in Figure 8-5 to Figure 8-9 show the valve opening times for the irrigation events between October 2015 and June 2017. Only sets 6 and 7 can be seen in the first part of Figure 8-5 because these two sets were instrumented with automation over two months before the rest of the farm in January 2016.

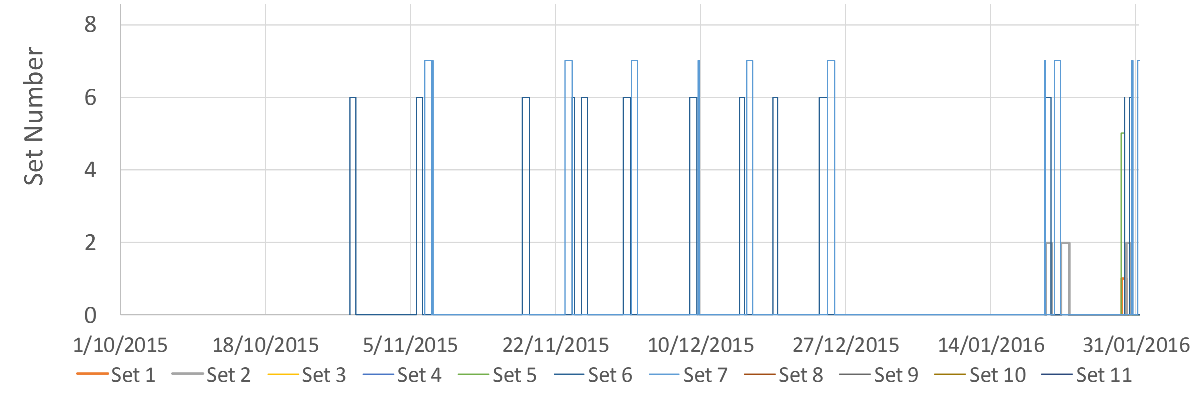


Figure 8-5 – Plot of valve opening times at Linton site for October 2015 - January 2016.

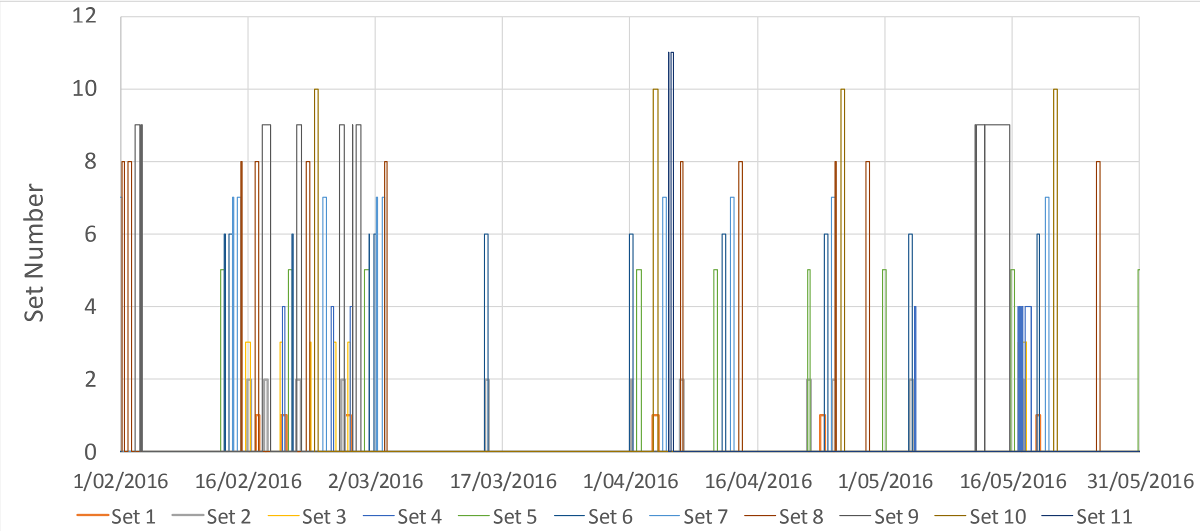


Figure 8-6 – Plot of valve opening times at Linton site for February 2016 - May 2016.

There is a general shut down between mid June and late August when there are no irrigations within the 11 furrow blocks as shown in Figure 8-7.

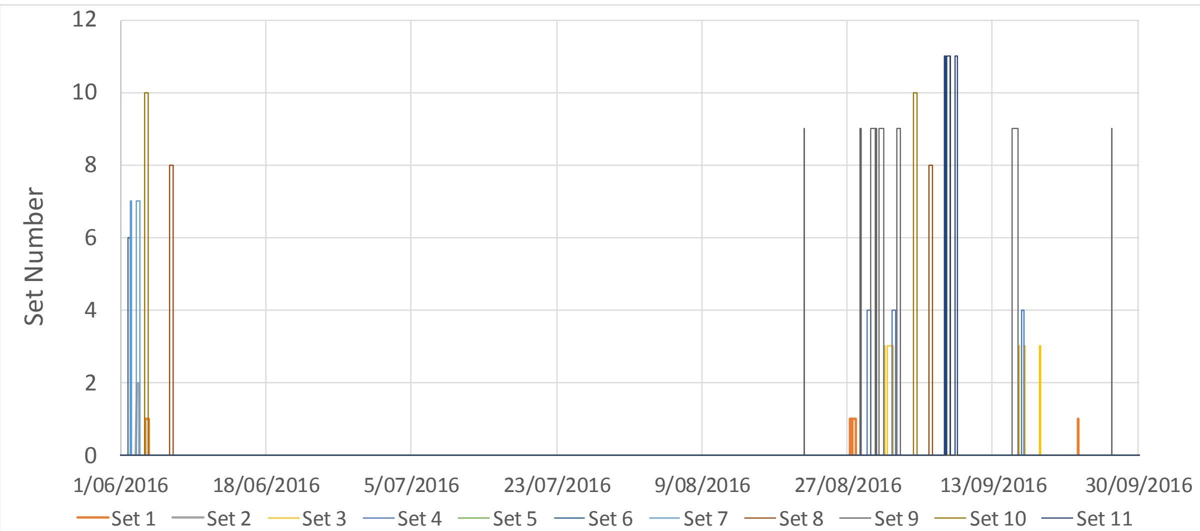


Figure 8-7 – Plot of valve opening times at Linton site for June 2016 - September 2016

The valve opening times in Figure 8-8 appear to be much shorter than for the previous figures, this is due to the fact that Aaron Linton is experimenting with surging for some of the blocks, which is discussed later. Figure 8-9 shows the last 5 months prior to the end of June 2017.

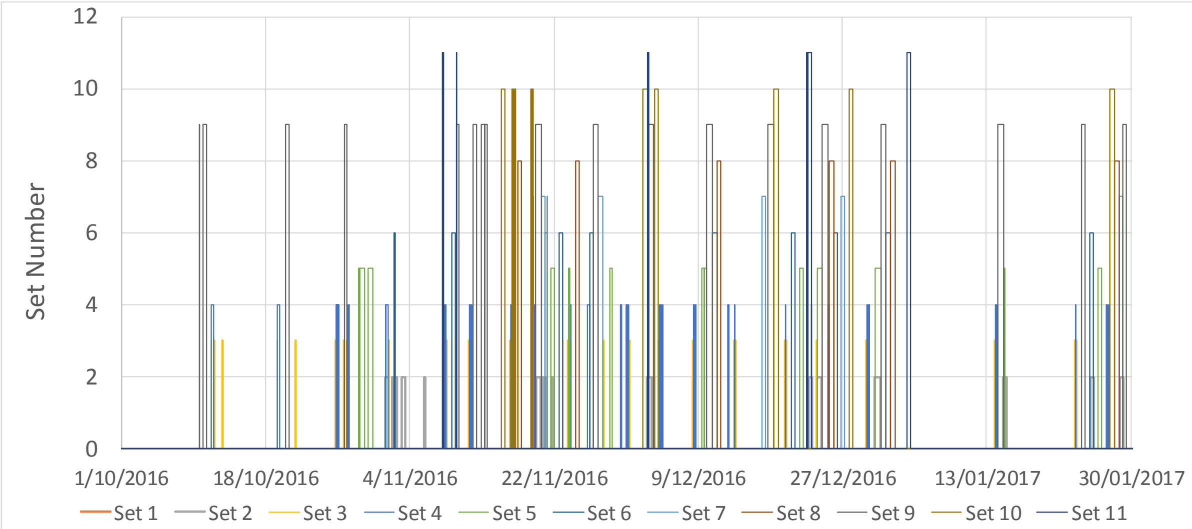


Figure 8-8 – Plot of valve opening times at Linton site for October 2016 - January 2017.

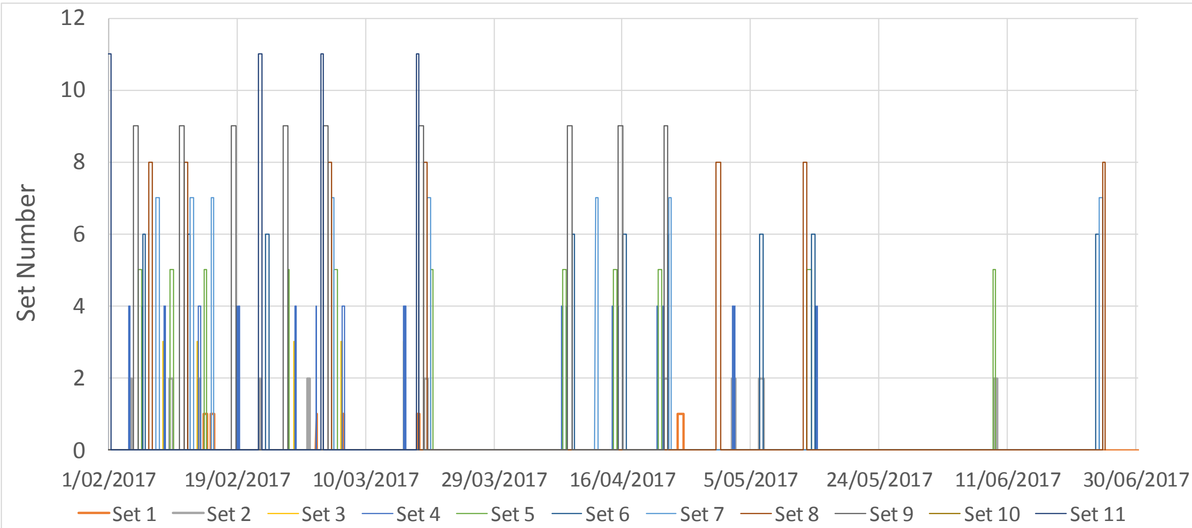


Figure 8-9 – Plot of valve opening times at Linton site for February 2017 – June 2017.

8.2.2. End of Field Drain Probe Data

As described in section 6.4.4, drain sensors were installed at three locations on the Linton farm in order to detect the runoff from the eleven irrigation blocks. The poor infiltration rates at this site mean that Aaron must normally run the irrigation for a number of hours after water reaches the end of the field, therefore detecting the time at which the runoff starts is not as important as for other farms. The farm design also allows the runoff from all fields to be captured in a single reuse storage which Aaron conveniently uses for the drip irrigation system so there is no need to minimise runoff losses. However, Aaron does value the ability to know how quickly water is reaching the end of the field as it indicates how the soil is behaving and he can potentially alter the schedule if the water is advancing too quickly.

The drain level sensors were installed at different times during 2016 but each has been performing well since this time. Table 8-5 provides a summary of the quantity of events where end of row times are available. There have been a total of 249 events since installation where the drain probes were clearly able to distinguish the start of runoff. On some sets such as 2, 5, 6, 7, 8, 9 the probes have almost detected every single event. The occasions when the probe failed to detect the runoff may have been the result of the irrigation being too short and no runoff occurring, or the drain may have already been full when the runoff commenced. This explains why set 4 has a poor detection rate, because set 3 was often irrigated immediately before block 4 and the drain was often still full of water, and many of the events on sets 3 and 4 were surges and may have not caused any runoff.

Table 8-5 – Summary of drain probe data at Linton Site Up to July 2017)

Set	1	2	3	4	5	6	7	8	9	10	11
No. of irrigations since drain probe installed	12	34	69	61	27	24	21	21	24	15	13
No. with runoff detected	9	31	60[1]	27[1]	26	23	18	18	22	13	1

[1] **When surging is practiced often runoff may not occur or it might be hard to detect**

The drainage probes at this site have worked well and demonstrate how a single sensor at the correct location can adequately detect up to 4 individual sets irrigated at different times.

8.2.3. Case Study - Surging

Two separate IrriMATE™ evaluations, one conducted by the project and the other by BPS, indicated that the soil suffers from infiltration problems. The water quickly advances over the length of the field, but only a small amount of water infiltrates into the soil, furthermore this infiltration does not move laterally into the bed. The evaluation performed on block 7 in April 2015 was conducted in 8 month old ratoon cane. The block was irrigated overnight with a duration of close to 12 hours and two valves were opened to reduce the flow from Table 8-4 down to 0.544 L/s. Despite this low flow, the water reached the end of the field between 2 - 4 hours after starting, and resulted in a large volume of runoff. The estimated deficit for this irrigation based on a full profile at the previous irrigation was 33 mm, the applied depth was 32.5 mm with only 20 mm of infiltration and 12.5 mm of runoff. Figure 8-10 shows a screen capture from the SISCO model run for this evaluation based on an average furrow where the green line represents the target and the red shaded area is the actual infiltration.

Aaron Linton, the grower, is well aware of this problem and the detrimental impact on the sugar yield. Aaron's own measurements found that drip irrigation on this soil had a higher yield but higher water use than the furrow irrigation. In the 2016 - 2017 season, Aaron trialled two approaches to mitigate this problem; green trash blanketing on the ratoon blocks and surge irrigation on the plant blocks.

Surge irrigation is a technique where the water is applied in an intermittent fashion rather than a continuous flow. Rarely practiced in Australia, this normally means manually switching valves every 1 to 2 hours. On certain soils, the wetting and drying cycles which occur with surge irrigation have been shown to reduce the soil infiltration rate and allow the water advance to reach the end of the field with a lower volume of water applied. This effect has been proven on a selected number of trials in the U.S. In this way, "Surge Irrigation" is used as a treatment for high infiltration soils, which is the opposite problem to what is occurring at the Linton site.

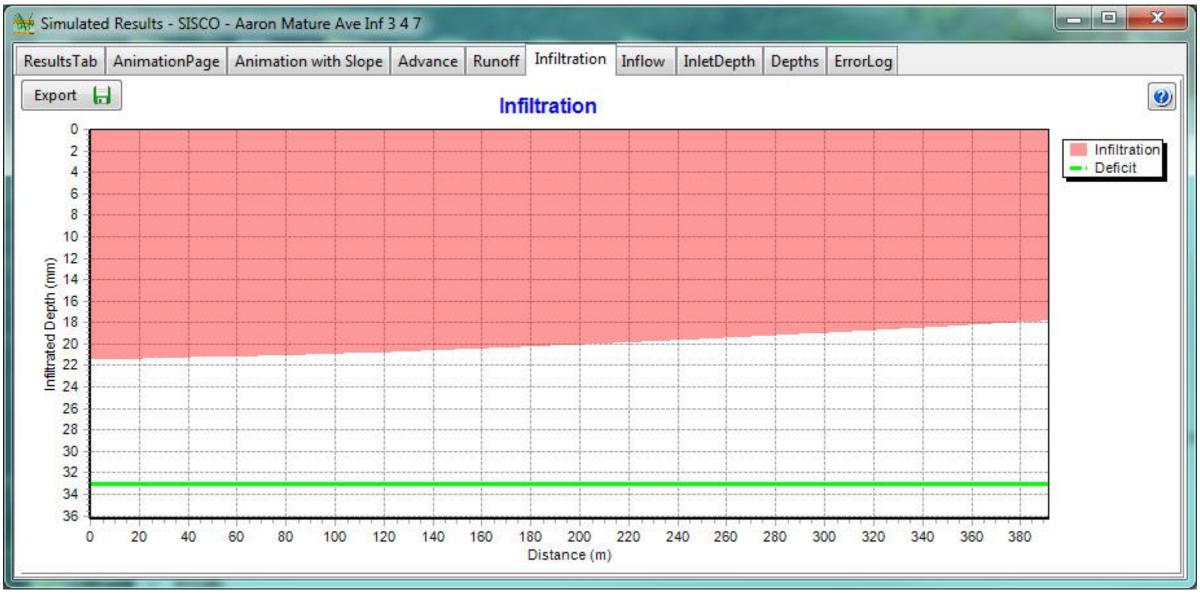


Figure 8-10 – SISCO evaluation on block

On blocks 3 and 4, Aaron has been adopting a surging style irrigation technique where block 3 and block 4 are irrigated on a one–hour-on one–hour-off schedule as shown in Figure 8-11, which represents an irrigation event which occurred on the evening of the 26/10/2016. In this case, Set 3 is irrigated for just over 60 minutes then set 4 for 60 minutes and back to set 3, this repeats for 5 cycles. The drain probe starts responding on the second cycle and by the third cycle runoff is occurring for each of the 60 minute surges.

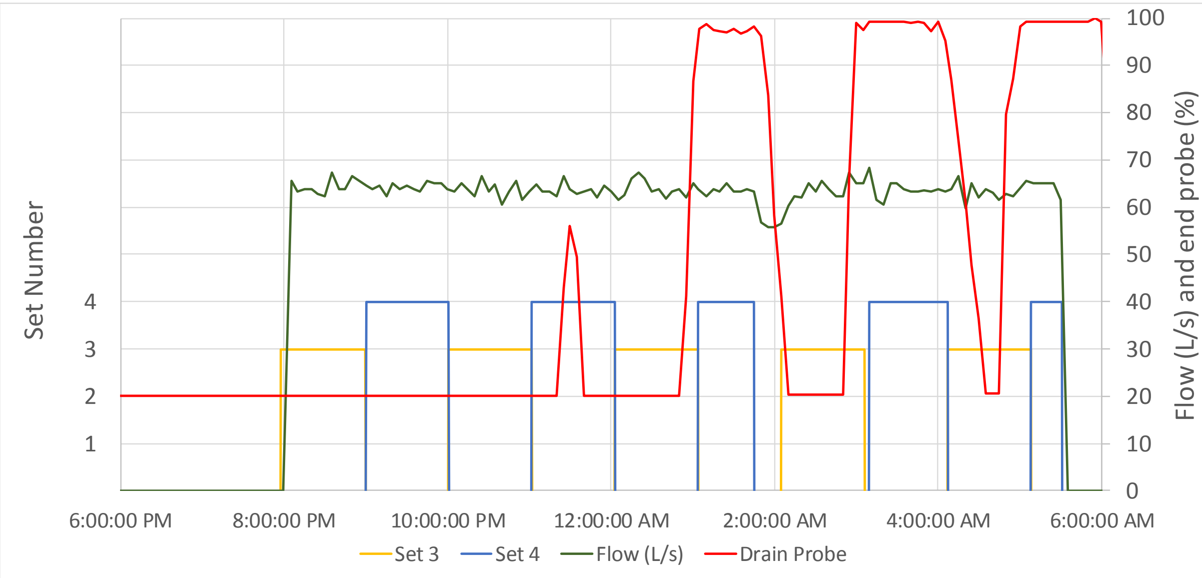


Figure 8-11 – Example surging on blocks 3 and 4 at Linton site.

It is uncertain whether the surging is having the desired effect but it is clear that the automation is now allowing Aaron to irrigate two or more blocks in one off peak period. This surging is something that would have never been possible without automation, particularly considering that this irrigation event is occurring during the night.

8.2.4. Case Study - Taking Advantage of Off Peak Power

Electricity for pumping is a significant cost for many irrigated sugarcane growers. Pumping costs per unit of water applied are lower for furrow irrigation than pressurised systems but growers in the Burdekin tend to apply a greater volume of water than in other districts due to the higher crop demand and plentiful supply. There are three ways to mitigate pumping energy costs, increase the efficiency of the irrigation system, improve the efficiency of the pump or in the case of electric pumping, optimise the use of the available energy tariffs. In Aaron's case, as described in section 10.4.2, based on measured pumping times over a single 12 month period it is possible to reduce the total electricity cost from $31.28 per ML down to $17.94 per ML by moving from the flat rate tariff 66 to the time of use tariff 62. Across the 53 hectares of automation this equates to a saving of $6,487 per annum or $122.40 per hectare.

These lower energy prices require use of off peak power periods which occur during times with lower general usage across the electricity grid. For example, for Tariff 62 the off peak times occur 9pm to 7am weekdays and all weekend. Under manual control this would require the grower to attend to the irrigation system during this off peak time. Hence only a limited number of furrow irrigators can take advantage of these alternative tariffs. Automation of the pumping and irrigation control system now allows growers such as Aaron to schedule the irrigations to occur during these periods without having to be at the site.

A good example of the effective use of the system to schedule irrigations during off peak times occurred in January and February 2017 as shown in Figure 8-12 where the shaded blue bars are the pump run times and the red lines represent the peak times. In this 2-month period, the total pump run time was 433.2 hours with only 6.1 hours (1.4%) of this occurring during peak times. These 6.1 hours in peak time were mainly a result of the schedule running 10 to 20 minutes past the end of the off peak period.

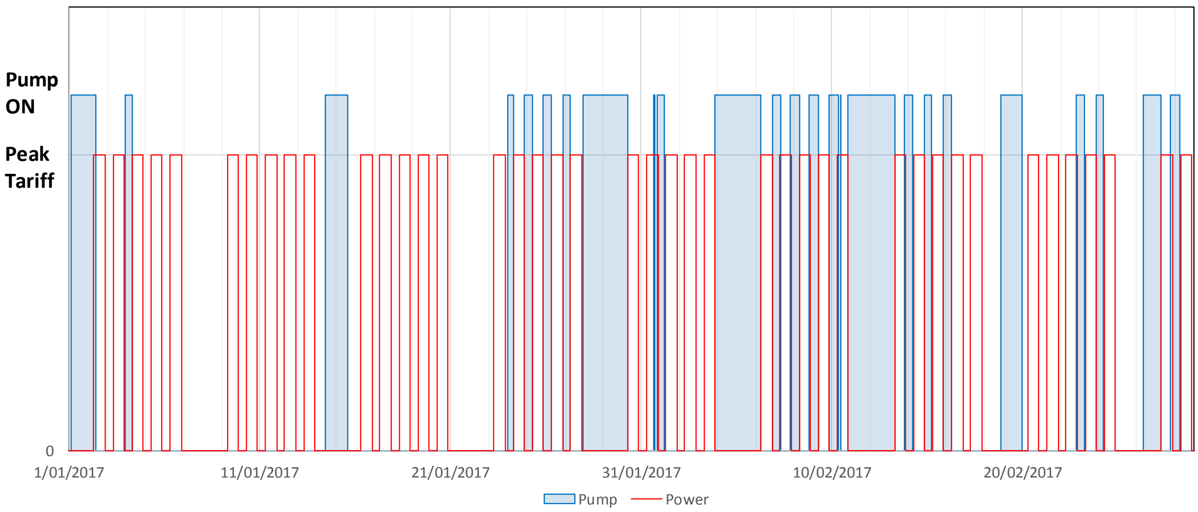


Figure 8-12 – Pump usage and peak power periods for Up River pump (blocks 3 to 11)

This same analysis of peak and off-peak time run times was repeated for each quarter between January 2016 and November 2017 as shown in Table 8-6. Pump 1 has been operated almost solely in off peak times since January with only 3% of the operating time being at peak tariff time. Pump 2 was still operated in both peak and of peak times until sometime in September 2016, thereafter it too has been predominately run in off peak times. Considering all usage of both pumps since October 2016, the run time has been 97.5% in off peak and only 2.5% in peak times. Aaron has done an impressive job in sticking to the off peak tariff time periods. Currently AquaLink does not manage this peak/off peak time automatically, Aaron has himself considered these times when designing the schedule. This opens up a possible future feature of the AquaLink software, the ability to override the hours that a pump is able to run, this eliminating the peak usage entirely.

Table 8-6 – Peak and off peak power usage at Aaron Linton's farm in hours

		2016				2017			
Date		Jan Mar	Apr Jun	Jul Sept	Oct Dec	Jan Mar	Apr Jun	Jul Sept	Oct Nov[1]
Pump 1	Peak	0.8	1.0	0.5	1.9	1.8	14.0	2.7	1.8
	Off Peak	118.3	114.5	17.4	131.4	136.1	66.7	112.7	108.3
Pump 2	Peak	206.9	102.4	73.6	27.8	8.8	7.2	4.6	4.1
	Off Peak	318.1	352.2	117.5	930.4	633.4	330.5	309.5	140.0
Total hours		644.1	570.1	209.0	1091.5	780.0	418.5	429.5	254.2
Total % peak		32.2	18.1	35.5	2.7	1.4	5.1	1.7	2.3

[1] **this is only ½ of a quarter year**

As indicated earlier, it is estimated that Aaron would be able to save up to $6,487 per annum or $122.40 per hectare based on current pump run times if he was able to switch from Tariff 66 to Tariff 62 and irrigate entirely in off peak times. This potential saving drops to $6,116 per year ($115.40 per ha) if 2.5% of the pumping time occurs in peak as was measured in the time since October 2016. Therefore, even if there is a slight overrun of pump usage into the peak tariff times there is still a significant saving when compared to the flat Tariff 66.

8.2.5. IrrigWeb Analysis

IrrigWeb is a web based irrigation scheduling tool designed specifically for sugarcane. IrrigWeb is a simplified version of the scheduling tool WaterSense (Haines and Attard, 2010, Inman-Bamber et al., 2008). Most crop water balance models are based on the well-established FAO56 technique for predicting crop water use which determines the atmospheric water demand and scales this according to a standard crop coefficient which is available for a range of crops. The problem is that these crop coefficients assume that the crop is growing under optimum conditions with no water stress. IrrigWeb and WaterSense are different in that they instead predict water use using a sugarcane crop model and can account for the impacts of soil, trash and water stress on crop water use.

The automation system provides the grower the ability to record the timing and volume of water which was applied with each irrigation event. Hence the system provides growers with the data which can be used to populate water balance models such as IrrigWeb. Currently IrrigWeb requires growers to manually transfer the data from the automation system to IrrigWeb but there is a current project to automate this data transfer.

The use of IrrigWeb is being investigated through the Smarter Irrigation project and therefore will be explained in greater detail in coming months with the documentation for that project. Some examples of the IrrigWeb data is presented in this report below.

8.2.5.1. Set No. 3 2016-2017 season (measured infiltrated depths)

Set number 3 has been chosen to illustrate use of IrrigWeb to model the crop water balance, note that set 3 was one of the irrigation sets where surging was tested throughout the season. This set was chosen as it has the highest number of irrigations of any block, a total of 69 events in this single sugarcane season.

For each set, AquaLink is recording the start and stop time of the irrigation, the flowrate over time during each event and the time taken for water to reach the end of the field. Combined with previous IrriMATE^{TM}/SISCO evaluations at this site it was possible to partition the applied depths into infiltration and runoff for each of the 69 individual events. As discussed in a previous section, this soil tends to have a low infiltration rate and therefore a large proportion of the applied water leaves the field as runoff, in this case over the 2016-2017 season around 1/3 of the applied water runs off the field with the remaining in the field as infiltrated depth.

IrrigWeb was configured with the following:

- Crop Type = Plant cane
- Meteorological site = Clare
- Rain = Aaron's rain gauge (at his farm connected to WiSA)
- Soil = Loam over sand PAW = 122mm
- Row config = 1.8m dual
- Deficit = 60mm
- Trash cover = 0%

A plot of the soil water balance from IrrigWeb for the measured irrigations on set 3 is given below in Figure 8-13. This figure shows both the irrigation and rainfall which occurred during the season and a continual plot of the predicted soil water balance. Observing this data at the end of the season helps researchers understand the response of the crop to the irrigation management but these tools are far more useful to the grower within the season to track the current soil water deficit and inform how they might be able to better meet the crop requirements.

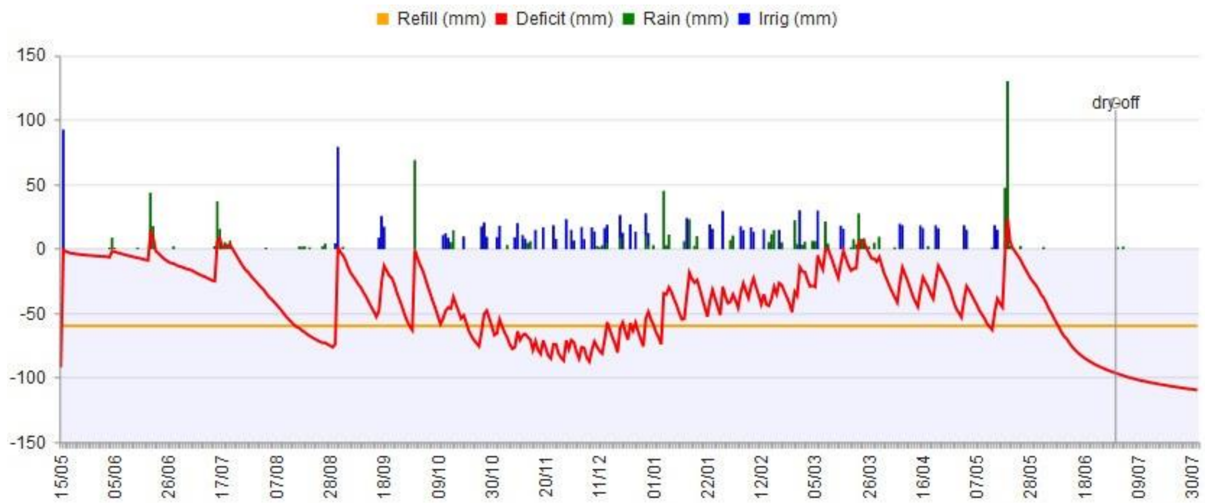


Figure 8-13 – IrrigWeb model run for set 3 (2016-2017 season) with measured infiltrated depths

8.2.5.2. Set No. 4 2016-2017 season (measured vs assumed manual application)

Set 4 will be used to illustrate the measured irrigations which occurred with the automation system as compared with what might occur under manual irrigation control. An irrigation rule is proposed to represent manual control:

- 30mm max application (based on the infiltration problems which were observed in the field measurements described in section 8.2.3)
- 10 day min cycle time (which attempts to reflect the fact that Aaron would probably irrigate 1 set a day under manual control and it would probably take around 10 days for an irrigation cycle).

Two sets of results are presented below, firstly the model run for the measured applications conducted with the automated system (Figure 8-14) which as above has subtracted the runoff losses from the applied depths, and secondly a model run following the manual control rules above (Figure 8-15). Here the manually controlled system is unable to keep up with the crop water demand because it is only able to apply 30mm each 10 days whereas the automated irrigation system is able to schedule events to occur more frequently thereby operating closer to field capacity and causing less water stress.

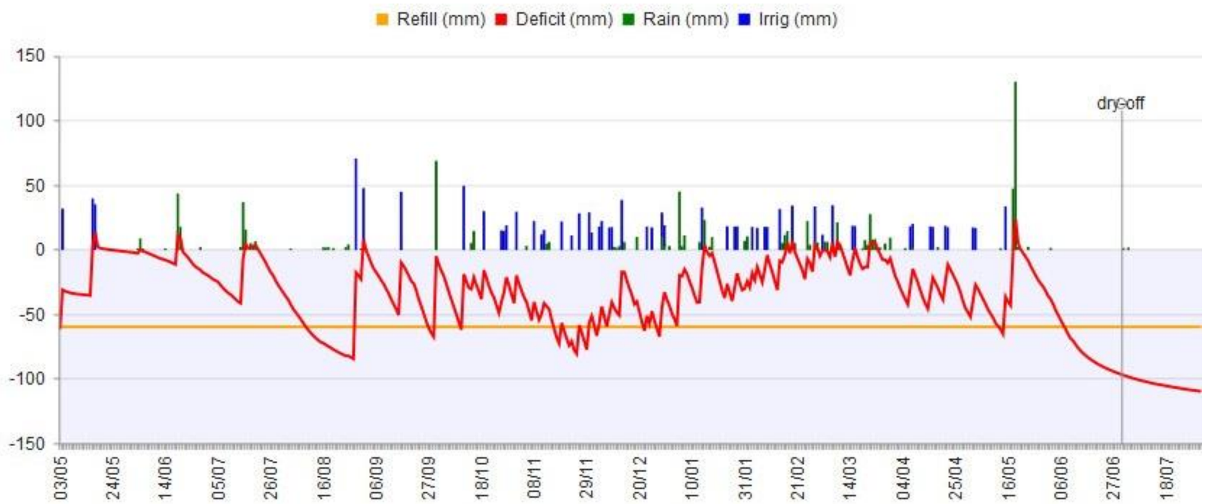


Figure 8-14 – IrrigWeb model run for set 4 (2016-2017 season) with measured infiltrated depths

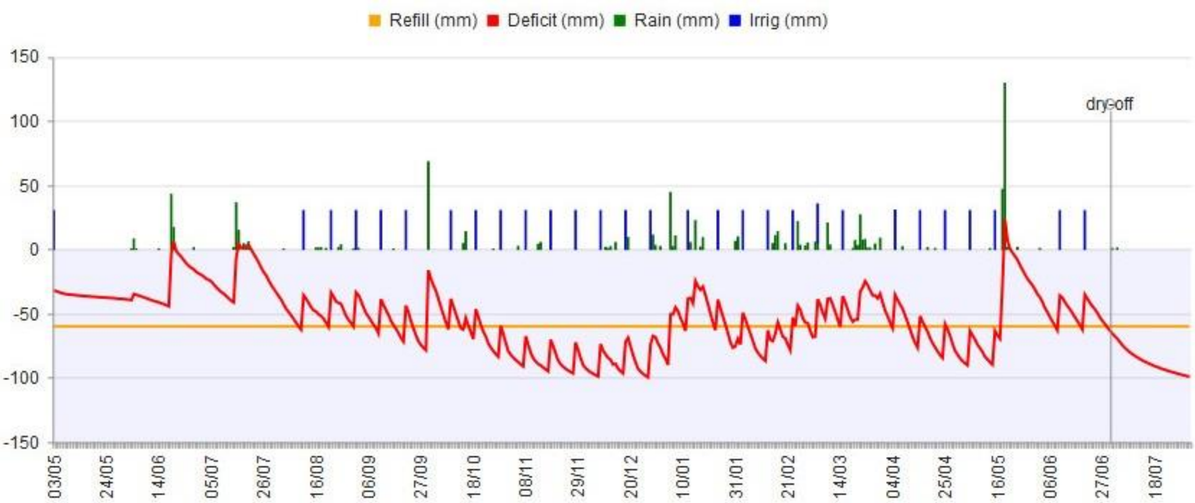


Figure 8-15 – IrrigWeb model run for set 4 (2016-2017 season) with predicted manual control

The cumulative result of stress is a reduction in sugarcane yield which IrrigWeb is able to predict. IrrigWeb predicts that the manually controlled irrigation schedule will have a yield which is 22 tonnes per hectare lower than the predicted yield under the measured irrigation schedule. This additional yield is entirely the result of better scheduling, i.e. in this case a greater volume of water applied in a timelier fashion. Similar results were observed when the same manual irrigation rule is applied to block 3 with a 16 tonne/ha yield reduction under the manual irrigation management.

8.2.5.3. Conclusion

These results from IrrigWeb have shown the potential of automation systems to provide the data necessary for crop water balance models such as IrrigWeb. Sets 3 and 4 are extreme examples with 69 and 67 events respectively during this single season, but even under the typical 20 – 25 events per season it is an arduous task to manually determine the depths applied to each block and enter this into the water balance model without the data provided by the automation system. Now that the automation system can accurately record the applied volumes and times, the project team will in the future look towards how best to partition the runoff and infiltration and how to easily upload this data into the crop water balance model.

8.3. Jordan Site

The results in this section will summarise the measurements collected up until the 01/07/2017 at the Jordan site.

8.3.1. Inflow and Head data

There have been a total of 103 individual irrigation events across the 5 blocks at this demonstration site up until the end of July 2017. This does not include short open times where the valve was opened for a test and does not separate those events where Russell has split the event into one or more shifts in the WiSA schedule. For example, there may be a small number of instances where Russell scheduled an initial duration but then had to add a few hours on the same block if the water had not reached the end, in this case this is counted as one event.

A summary of the data is given in Table 8-7 and a plot of the valve opening times is given in Figure 8-16 to Figure 8-20.

Table 8-7 – Irrigations since automation was installed at the Jordan site.

Block	1	2	3	4	5
No. irrigations since automation	26	22	21	10	24
Average set flow (L/s)	106.9	115.0	141.4	148.0[1]	132.7
Average furrow flow (L/s)	1.32	1.42	1.79	1.85	1.66
Median Time (hrs)	18.7	24.6	14.0	14.1	35.4
Average Head (m)	0.797	0.790	0.740	0.770	0.770

[1] A limited number of events were collected in block 4 since installation of Starflow so this flow is largely based on the individual furrow inflow

There have been over 20 irrigations on 4 out of the 5 blocks. There are fewer irrigations for Block 4 than compared to the others as this block was fallow over the 2016/2017 summer. The total flow per block and furrow is lowest for blocks 1 and 2 but higher for the other blocks. The only explanation for this is that the ground surface on the headland is sloping towards the North (towards block 6). In a similar manner, the furrow flows are also lower in the first two blocks and highest in blocks 3 and 4.

Unlike for Pozzebon and Linton, the head in the cylinder does not vary much between the different sets. This is understandable when it is considered that the water level in supply channel just upstream of this point is maintained at a constant height.

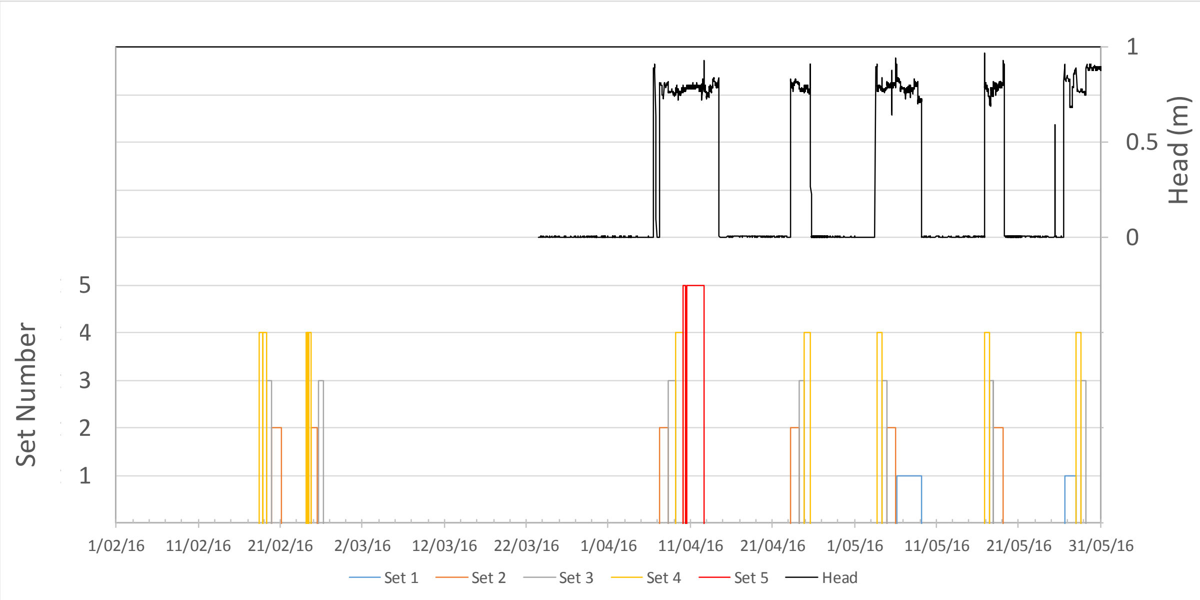


Figure 8-16 – Plot of valve opening times at Jordan Site for Feb – May 2016.

The PST level sensor stopped responding in August 2016 (Figure 8-17) but was replaced in October (Figure 8-18).

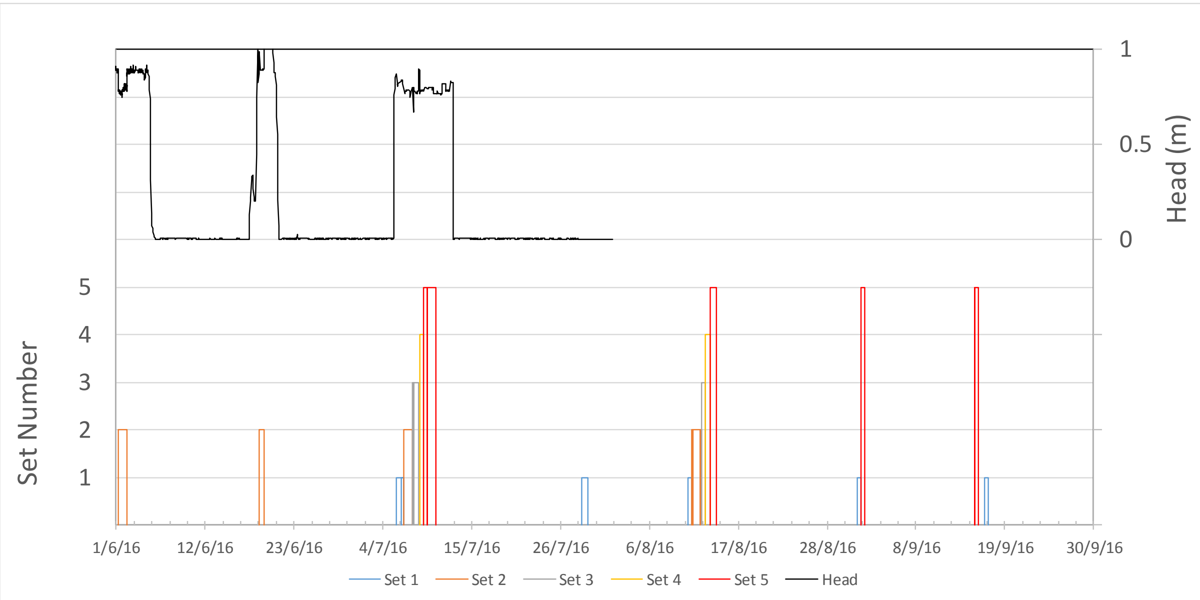


Figure 8-17 – Plot of valve opening times at Jordan Site for June – Sept 2016.

During the Summer of 2017, Russell gained confidence with the valves and therefore was happy to leave the channel intake open between irrigations which is shown by the fact that the water head does not decline to zero between irrigations (Figure 8-18 and Figure 8-19).

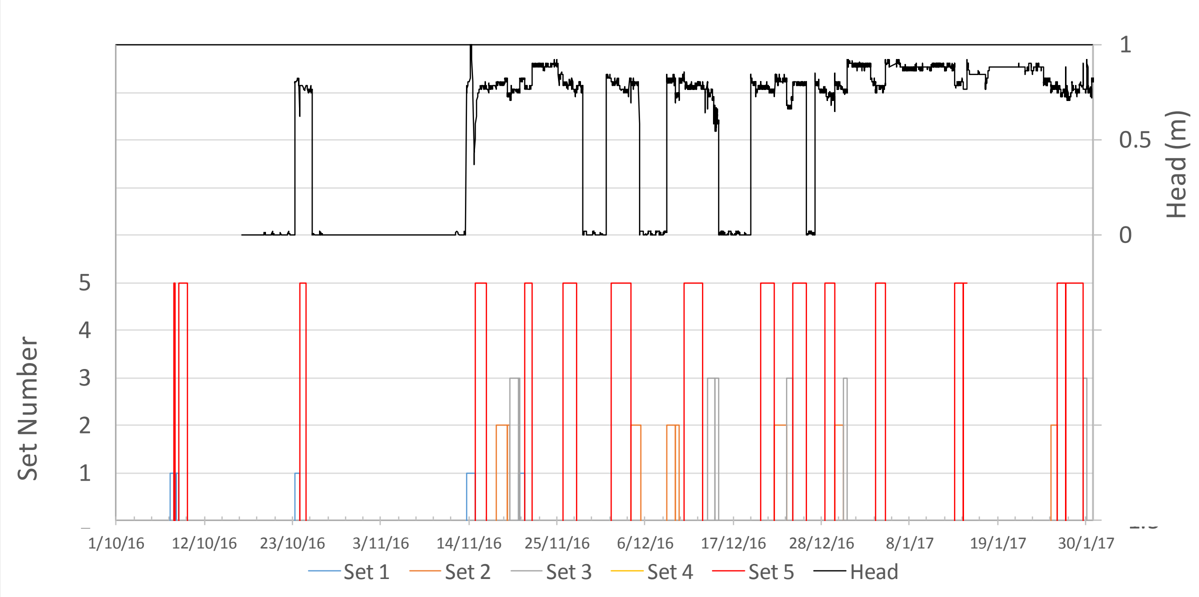


Figure 8-18 – Plot of valve opening times at Jordan Site for Oct 2016 – Jan 2017.

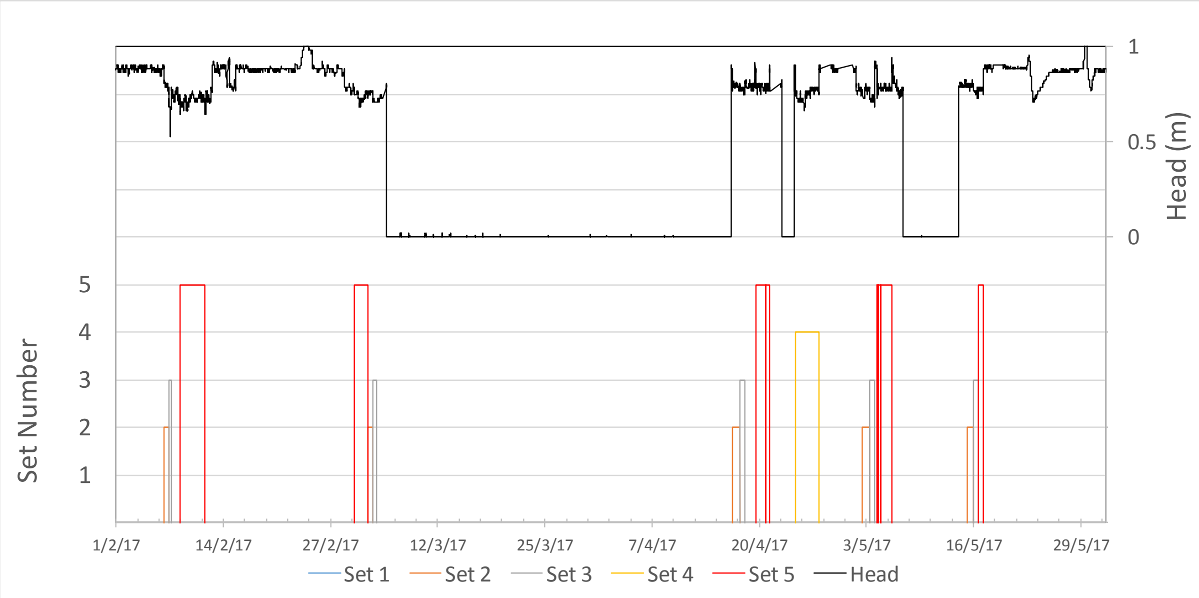


Figure 8-19 – Plot of valve opening times at Jordan Site for Feb – May 2017.

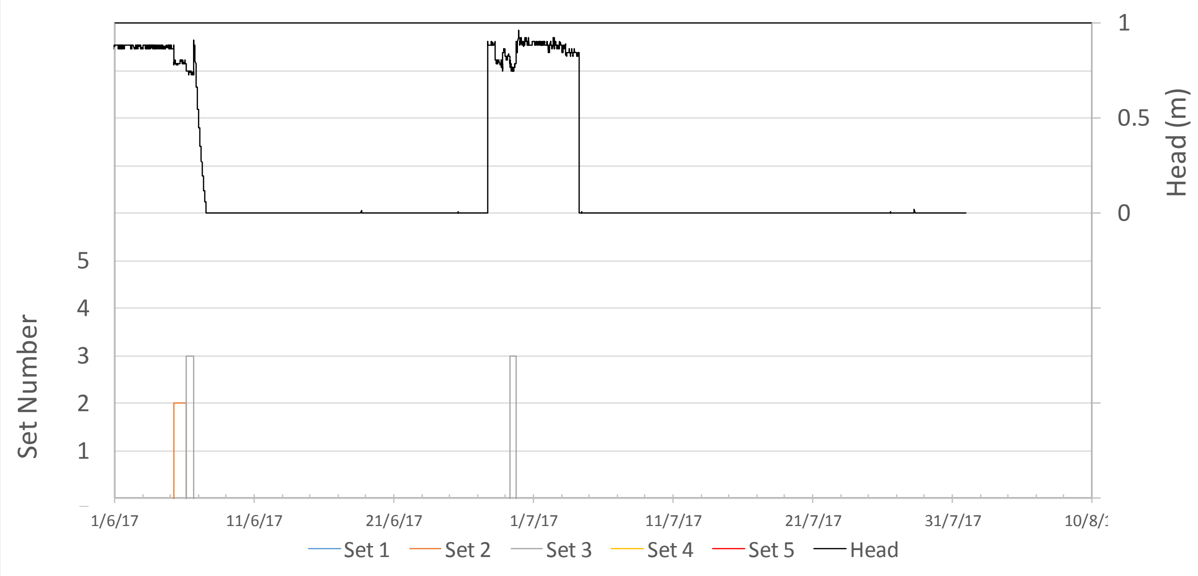


Figure 8-20 – Plot of valve opening times at Joran Site for Jun – Jul 2017.

8.3.2. Sample Data on Irrigation performance

These automation systems allow the measurement and collation of irrigation performance data on a scale which has never previously been possible. Previously, measurements of irrigation performance such as the IrriMATE^{TM} analysis were restricted to a single event and researchers and industry extension staff were forced to extrapolate these results out to an entire season by assuming that all irrigations in that season behaved in a similar manner. This is a simplistic assumption but was necessary because of the difficulty in collecting measurements over the entire season. This section will aim to present some samples of the analysis which is now possible at the Jordan site due to the installation of the automation system.

8.3.2.1. Sample Analysis of single event, Set 1 27/12/2016

The flow and end of field advance time collected by the automation system permit use of a simplified version of the IrriMATE^{TM} analysis technique. One event from the middle of the season on set 1 will be selected to illustrate this process.

The valve on set 1 opened at 27/12/2016 at 6:10 am and closed on 18:27 pm on the same day with a duration of 737.3 minutes as shown in Figure 8-21. The Starflow measured an average flow of 103.22 L/s or 1.358 L/s per furrow during the event. There was no significant variation in the pressure head during the event so it can be assumed that the flowrate was constant and the scatter observed in the Starflow data is a result of the measurement process.

The advance probes detected the water advance at 592 minutes at 1080 m and 718 minutes at 1256 m. The advance time for this irrigation was shorter than for most other events on this set, indicating that the infiltrated volume is low. The advance data was entered into SISCO (Figure 8-22 a) which combined with the flow, previous full IrriMATE^{TM} evaluation on this field and site characteristics was able to predict the infiltration function.

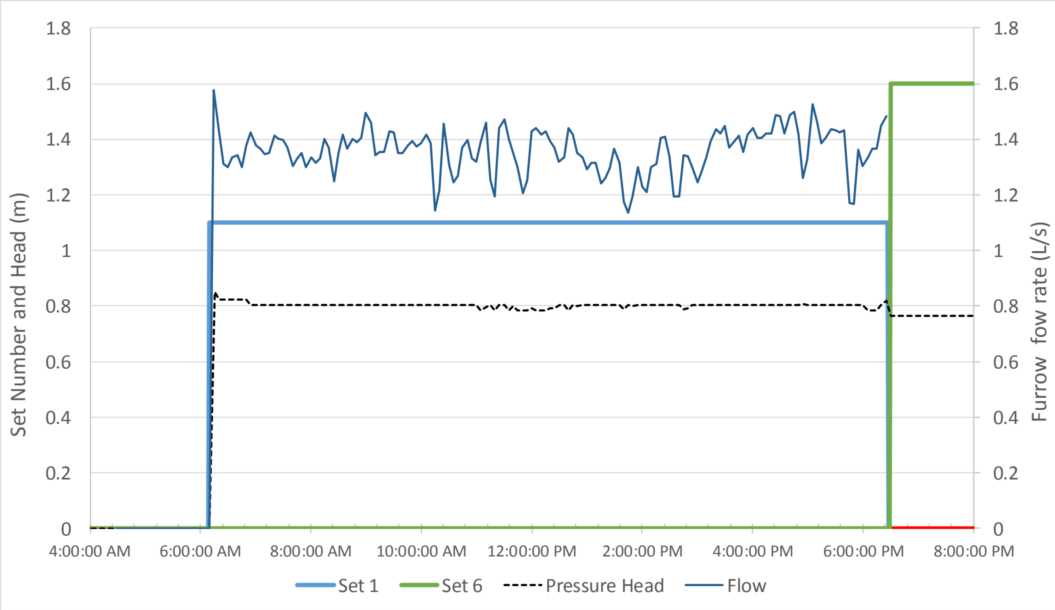


Figure 8-21 – Example irrigation - Jordan, Set 1, 27/12/2016

This irrigation, like many of the events in block 1, experienced a low infiltration rate. The curve (Figure 8-22 b) indicates that only 25mm of infiltration can be expected after a ponding time of 900 minutes. The subsequent SISCO model run to predict irrigation performance (Figure 8-23) shows that the irrigation was unable to replenish the 136 mm deficit (from IrrigWeb) and therefore there is no deep drainage from this event.

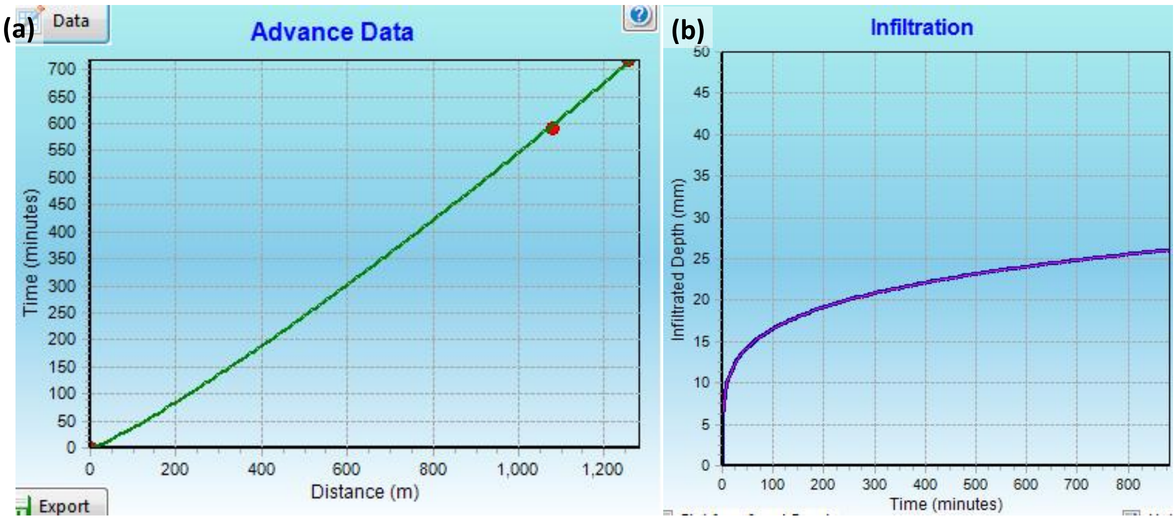


Figure 8-22 – (a) Fitting SISCO to advance data and (b) the resulting infiltration function

Following successful calibration of SISCO, the model was used to evaluate the irrigation performance with the following results:

Applied depth = 30.7 mm
Infiltrated depth = 24.8
Deep drainage depth = 0.0 mm
Runoff depth = 5.9 mm

A plot of the applied depths across the field length is shown in Figure 8-23 where the inability to satisfy the soil moisture deficit is clear.

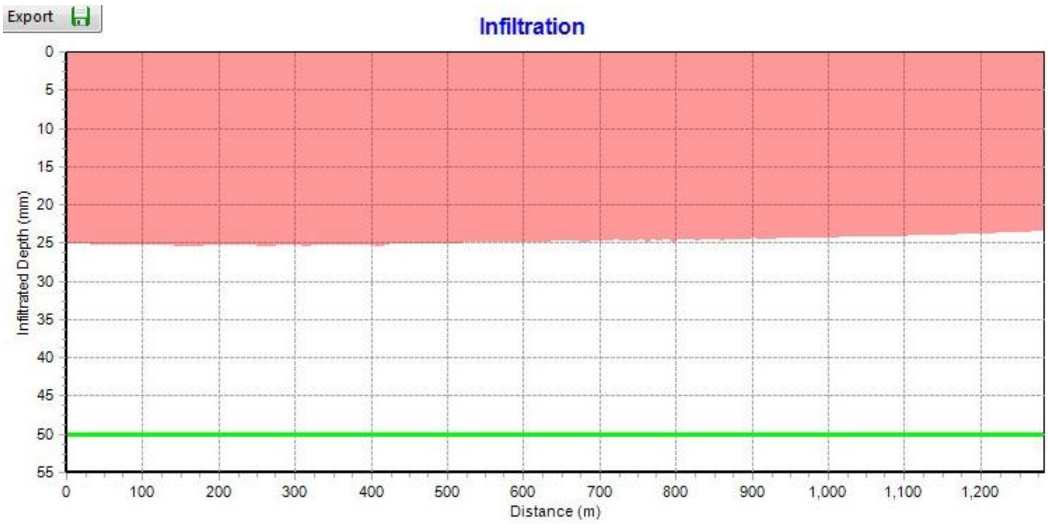


Figure 8-23 – Infiltrated depths predicted by SISCO for irrigation of Block 1 on 27/12/2016

This same procedure has been completed for all 5 blocks in this field across all irrigations where end of row advance data is available.

8.3.2.2. Set 1 across the season

This single event above is one of the 26 irrigation events which occurred on set 1 at the Jordan site during the 2016-2017 season. This set was planted on the 3/03/2016 and therefore all irrigations in that cropping cycle have been completed using the automation system, hence there is a record of all irrigations in terms of irrigation duration, water head and for most irrigations, the flowrate. A summary of all events during the 2016-2017 season on set 1 is given in Table 8-8. The data provided is presented as an example of the analysis which is possible by extracting the measurements collected by the automation system.

The system has recorded the valve opening and closing times for all irrigations since planting, with the resulting “Inflow Time” in the table. In a small number of cases the channel offtake was opened after the valve time, this has been corrected using the measured pressure head measurements. The Starflow has recorded the inflow hydrograph and hence volume applied for every irrigation since the middle of September 2016 when it was installed. The flows prior to this date have been estimated based on the known flows after September. The “Depth Applied” expresses this total applied volume (infiltration and runoff) in terms of a water depth assuming that this is spread across the entire block area. The irrigation event corresponding to the example SISCO analysis shown above on the 27/12/2016 is shaded grey.

The SISCO columns are blank for those irrigations where no sensor was installed to detect the advance (e.g. prior to 09/2016) or when the water did not reach the end of the field which occurred in some of the smaller irrigations. The data from Table 8-8 was entered into IrrigWeb to track the water balance over the entire season, a plot of this IrrigWeb model run is given in Figure 8-24.

Table 8-8 – Summary of irrigations at Set 1 of Jordan site during the 2016-2017 season

Start Time	Flow (L/s)	Furrow Flow[2] (L/s)	Inflow Time (min)	Depth Applied (mm)	IRRIGWEB deficit (mm)	SISCO Infilt (mm)	SISCO Runoff (mm)
6/05/2016 3:50	[1]109.2	1.437	4401	193.7	56		
26/05/2016 17:00	[1]109.2	1.437	2004	88.2	51		
5/07/2016 17:30	[1]109.2	1.437	1277	56.2	33		
28/07/2016 14:03	[1]109.2	1.437	1208	53.2	14		
10/08/2016 18:04	[1]109.2	1.437	777	34.2	37		
31/08/2016 18:00	[1]109.2	1.437	720	31.7	56		
16/09/2016 12:33	109.0	1.434	724	31.8	76	21.5	10.3
7/10/2016 18:00	116.8	1.537	1441	67.9	115	67.7	0.1
23/10/2016 6:22	110.1	1.448	876	38.9	111	34.0	4.8
13/11/2016 17:30	108.4	1.426	1472	64.3	134	64.3	0.0
20/11/2016 5:21	103.7	1.365	1148	48.0	105	35.7	12.3
25/11/2016 5:04	100.4	1.321	826	33.4	102	19.6	13.8
1/12/2016 5:29	100.5	1.323	771	31.2	118	21.8	9.4
10/12/2016 6:07	110.3	1.452	1008	44.8	130	30.3	14.6
19/12/2016 5:53	105.0	1.381	892	37.8	131	23.5	14.2
27/12/2016 6:10	103.2	1.358	737	30.7	136	24.8	5.9
3/01/2017 5:58	102.0	1.365	732	30.6	136	20.9	9.7
24/01/2017 18:00	105.2	1.399	1460	62.6	56	62.5	0.0
30/01/2017 20:24	102.8	1.352	1095	45.4	31		
7/02/2017 15:41	97.8	1.287	1462	57.6	19		
12/02/2017 12:08	106.0	1.395	171	7.3	20	7.3	0
14/02/2017 18:00	103.5	1.362	1042	43.5	28		
28/02/2017 18:00	103.4	1.360	1586	66.1	28		
18/04/2017 7:23	109.4	1.440	1774	78.3	89	74.6	3.6
1/05/2017 18:00	113.3	1.490	1176	53.7	75	45.0	8.6
14/05/2017 6:00	111.0	1.460	1421	63.6	77	45.9	17.6

[1] Estimated using the flows collected after installation of the Starflow
[2] For most of the season Russell was irrigating 76 furrows out of the 81 in the set

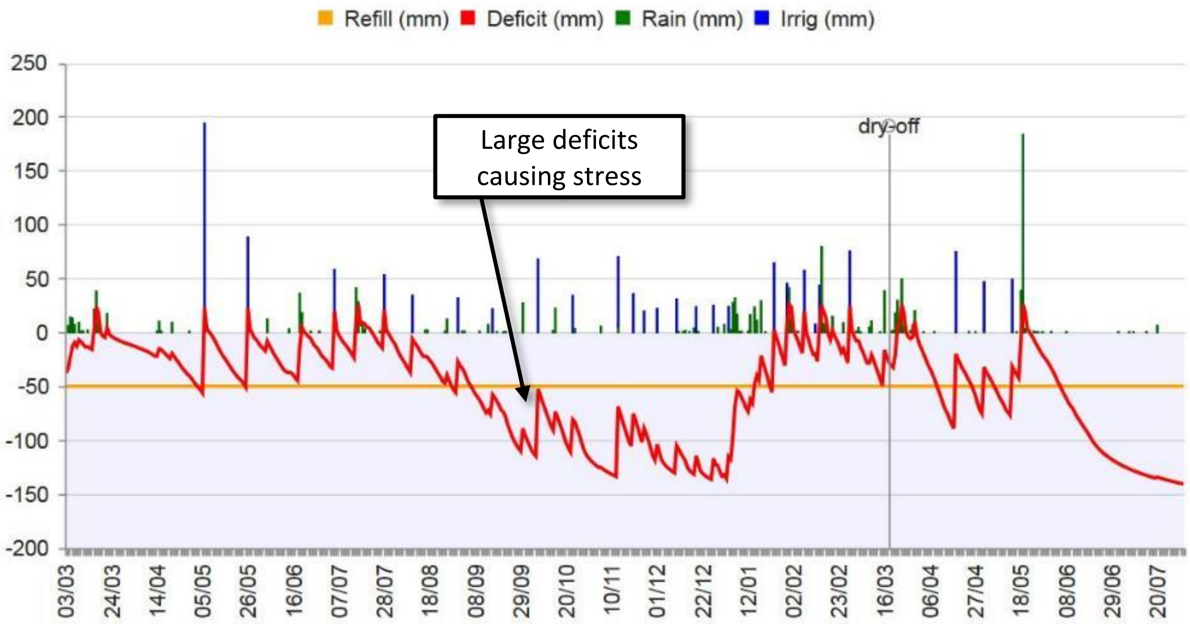


Figure 8-24 – IrrigWeb model run for set 1 (2016-2017 season) at Jordan site

In this set there is a large discrepancy between the soil moisture deficit (IrrigWeb) and the depth of infiltration. For many of the events from November onwards, the irrigation is only able to replenish part of the crop requirement (Figure 8-24). This is an important observation for both the grower and for the wider industry. The general practice with irrigation scheduling for furrow irrigation is to assume that the soil reaches field capacity and the deficit is reduced to zero after each event. This is clearly not occurring in block 1 and instead the deficit is becoming larger and larger with each event and only recovers after a rainfall event in January.

The IrrigWeb analysis shows that the irrigations are not adequately filling the profile between October and January in the peak growing season. This would cause a crop stress and reduce the sugarcane growth rates, reducing the yield. IrrigWeb suggests a potential gain of up to 19 tonnes per hectare if the soil moisture deficit is maintained within 50mm of field capacity. It is suggested that improved irrigation scheduling should achieve at least part of this potential yield improvement, and hence a modest 5 tonnes per hectare gain is used in the cost benefit analysis.

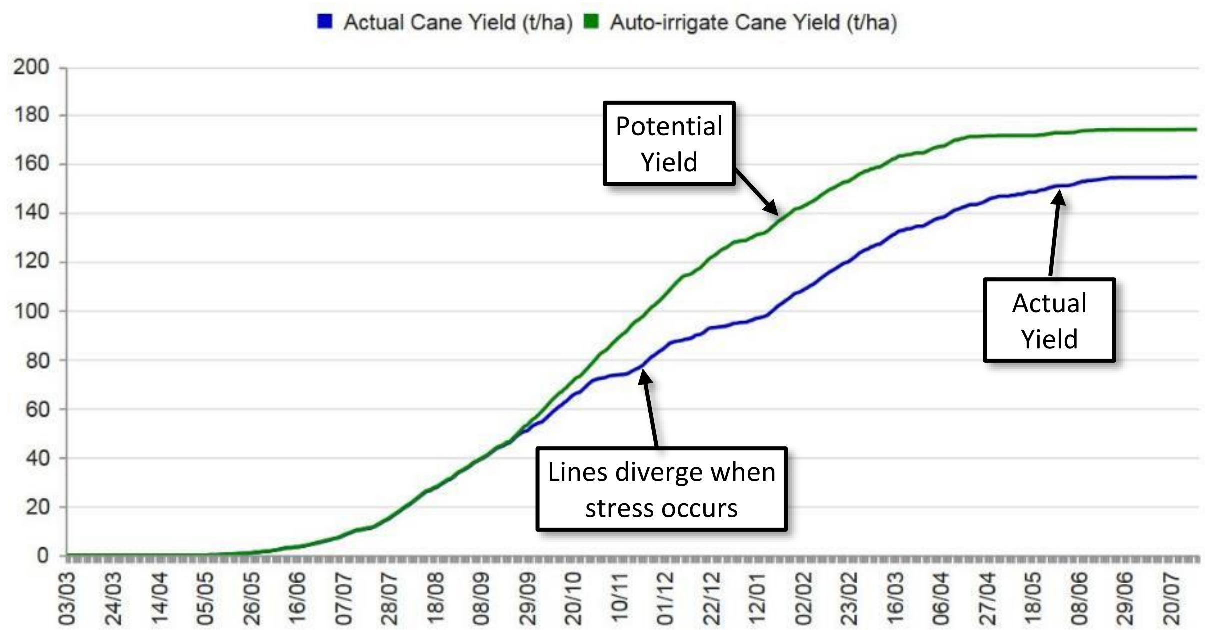


Figure 8-25 – IrrigWeb model run for set 1 (2016-2017 season) at Jordan site, actual yield and potential yield

The data presented in Table 8-8 and the IrrigWeb modelling shown in Figure 8-24 illustrates the potential of automation systems to provide accurate information on applied depths, which is essential for tracking the soil water balance.

8.4. Conclusion

This section has presented a number of examples of the types of data which can be potentially collected by the automation system. All examples presented were from WiSA systems but some of the alternative systems will have similar capacity in terms of their ability to monitor and record the behaviour of the automation system.

The automation system has demonstrated that it can provide a continual record of system flowrates, operating pressures and irrigation times over the entire season. The grower can look back over previous weeks, months or years to observe operation and performance of the system. Previously growers may have been able to determine the volumes of water used on a whole field scale based on scheme flowmeters but had no ability to partition this use down to an individual field or set level. Set level information allows growers to conduct their own benchmarking to determine the water use efficiency down at the variety, soil and management unit scale.

The data collected by the system will have immense value in terms of record keeping when growers are under increasing pressure to document farm management. Programs such as Smartcane BMP compliance are a formal recognition that growers are actively engaging with the principles of sustainability and minimising adverse environmental outcomes. Rather than growers attempting to estimate water use, automation systems will empower growers with the data they need to accurately determine water use at the irrigation set level.

The Linton site has demonstrated that automation permits the grower to take advantage of time of use tariffs and investigate alternative irrigation strategies such as surge flow irrigation. This data justifies the assumptions that the automation system allows growers to switch to alternative power tariffs that involve off peak power prices.

These data sets collected by the automation system now permit performance evaluation of furrow irrigation on a scale which has never been practically possible or has even been attempted in research studies. The combination of inflow rates and end of field advance times permits an analysis of infiltrated depths and runoff volumes from every irrigation in the season. The ability to measure applied volumes and infer infiltrated depths provides accurate data which can be used in irrigation scheduling tools such as IrrigWeb. IrrigWeb was used to demonstrate that yield increases would be possible with improved irrigation management strategies, which supports the scenarios in section 10 which associate a monetary value to this yield impact.

9. RURAL RESEARCH AND DEVELOPMENT FOR PROFIT – SMARTER IRRIGATION PROJECT 2A

9.1. Introduction

The Smarter Irrigation program is a cross industry initiative with participation and funding from the Australian Cotton, Dairy and Sugar Industries. More specifically, the NCEA currently leads a subset of this program titled: ***Smart Autonomous Irrigation - Develop precise and automated control systems for a range of irrigation systems***

The purpose of this chapter is to outline some of the ongoing activities in the Smarter Irrigation Project which relate directly to the sites established in the SRA Modernisation of Furrow Irrigation project.

The objectives of the Smart Autonomous Irrigation project are to:

a) Design and describe a fully autonomous broad acre irrigation system for adaptive precision irrigation of furrow irrigated cotton and sugarcane, and centre pivot irrigated dairy pasture and cotton.
b) Use existing commercial suppliers of automated broad-acre irrigation components and integrate for adaptive precision irrigation control with VARIwise software (McCarthy et al 2011) in large trials in cotton, sugarcane and dairy pasture.

The four primary sites for this project are:

1. Furrow irrigated sugarcane in the Burdekin (Jordan site)

Automation of an 82 ha sugarcane field under conventional furrow irrigation west of Ayr on the Burdekin Haughton irrigation scheme.

2. Lateral move irrigation of cotton on Darling Downs

Variable rate lateral move irrigating 102 ha of cotton south west of Dalby in QLD. Lachie and Neil Nass's property at Yargullen, eastern Darling Downs.

3. Furrow irrigated cotton in the Namoi Valley

Automated furrow irrigation using double head ditch and small PTBs. Carolan Family cotton and grain property, "Waverley", NW of Wee Waa, Lower Namoi, NW NSW.

4. Centre Pivot on dairy pasture in Tasmania

Variable rate centre pivot irrigation machine irrigating dairy pasture. TIA UTas Elliott Dairy Research Farm, Burnie, N. Tasmania, and Nigel Brock's dairy farm at Montana.

In simple terms, the Smarter Irrigation project aims to build on the automated furrow irrigation system installed at these sites with the ultimate aim of striving for an autonomous system which can sense the soil, climatic and crop and automatically develop and implement optimal irrigation management decisions.

9.2. Precision Irrigation

Precision irrigation, once a term used to describe drip irrigation, is defined as applying precise amounts of water to crops, at precise locations, at precise times, which might imply uniform application over the field (Smith and Baillie, 2009). A better definition was given by Smith et al. (2010) who conceptualised that a precision irrigation system is one that can:

1. Determine the timing, magnitude and spatial pattern of applications for the next irrigation to give the best chance of meeting the seasonal objective (i.e. maximisation of yield, water use efficiency or profitability);
2. Be controlled to apply exactly (or as close as possible to) what is required;
3. Through simulation or direct measurement knows the magnitude and spatial pattern of the actual irrigation applications and the soil and crop responses to those applications; and
4. Utilise these responses to best plan the next irrigation.

The components, scale and form of this system may vary depending on the irrigation application system type but there is no reason why this concept does not apply to all forms of irrigation. The main difference between surface irrigation and more precise application techniques is the size of the management unit. For example, variable rate centre pivot irrigators may be able to vary water application on the scale of several metres but for surface irrigation the minimum control size may be in the order of hectares. Conventional irrigation management, including surface irrigation, strives for uniform application. A key concept of precision irrigation is that the irrigation system should be able to spatially vary the application to achieve the best result in terms of crop yield, quality or profit.

The ultimate aim of the irrigation system is to apply water where and when it is needed by the crop. Automated systems provide a tool which facilitates this aim and offer the potential for management decisions to be made autonomously. A smart autonomous irrigation system is defined here as precision irrigation which is being achieved through use of an irrigation automation system. The concept of smart autonomous irrigation is still in its infancy, with limited commercial applications, but a great amount of scientific interest.

9.3. The Smarter Irrigation Sugarcane Site

An important part of the Smarter Irrigation project was the establishment of at least one demonstration site in each of the industries. All three automation sites were considered as potential candidates but it was the Jordan site which was chosen as being the most suitable for a number of reasons. Firstly, the site was fully automated and the system included flow measurement which is a crucial requirement of a precision system. Secondly, out of the three farmers it was Russell who was the first grower to embrace the idea of having the system automatically respond to measurements in the field, i.e. the end of row advance sensors.

There are 6 blocks at this site of approximately equal area, five of which are automated. The blocks are numbered 1 to 6 starting from the southern end of the field as shown in Figure 6-33. While the SRA project has dealt with 5 blocks this Smarter Irrigation project instead focusses on one block at time. During the 2016-2017 irrigation season, block 3 was selected as it was one of the blocks that was ratooned and the timing of harvest allowed EM38 soil survey and soil characterisation to be performed.

Block 3 is scheduled to be harvested in October 2017 and possibly replanted in the following year, therefore the project was forced to move to a new block. Block 1 was chosen as the focus for the 2017-2018 season.

9.4. Capturing Field Variability

Soil properties vary at all scales, from kilometres down to the sub metre level. These variations often have a significant impact on crop growth or in the case of surface irrigation, the performance of the irrigation system.

When walking through the field in early 2016 there were differences in crop growth along the length of the field. It was not known at that stage if this was the result of a soil change or was a result of some other factor. Historic Google Earth images showed crescent shaped bands traversing across the rows which at the time were thought to be possible evidence of prior stream paths, which made sense considering the close proximity of this site to the Haughton River. These assumptions were confirmed by anecdotal claims from the operators of BMS Lasersat who have observed similar behaviour on neighbouring properties where bands of sandy, lighter soil are seen though fields on this part of the BHWSS. In November, in the days immediately after harvest, BMS Lasersat were contracted to conduct a soil survey across block 3, the chosen block of the Smarter Irrigation project. The first stage of the survey involves an EM38 and field elevation grid collected over the entire field, which informs the operator of the locations to conduct detailed soil measurements and soil samples for chemical analysis. The end result is a spatial map of:

- Soil texture (Clay and sand percentages)
- Compaction
- Depth to root restriction
- Plant available water (PAW) at 5 depths up to 1200 mm
- Root zone PAW
- Root zone field capacity and permanent wilting point
- Nutrients and chemical properties at topsoil and subsoil depths including Calcium, Magnesium, Potassium, Sodium, Nitrate, Sulphate, organic matter, pH, Salinity, Boron, Copper, Iron, Manganese, Zinc

The survey of the field (Figure 9-1) measured an approximate drop of 2 m over the field length of 1,285 m giving a field slope of 0.001556 or 0.156% which matches well with a previous survey on block 5 with a slope of 0.00154. The grade of the field is reasonably uniform apart from some small patches around one third of the distance from the top end of the field with possible reverse slopes as shown in a plot of the aspect in Figure 9-2. The fact that these aspect changes are not visible in the elevation plot indicates that they are small relative to the field slope. Russell discussed how, when he purchased the farm, there were parts that did not irrigate or drain properly. This block has not been levelled or replanted since this time. Russell tried to rectify this on a previous ratoon using a RTK GPS to reform the furrows so that they have a constant downhill grade. Figure 9-1 and Figure 9-2 indicate that he was mostly successful but the grade would be improved further if the field is levelled during the next replant.

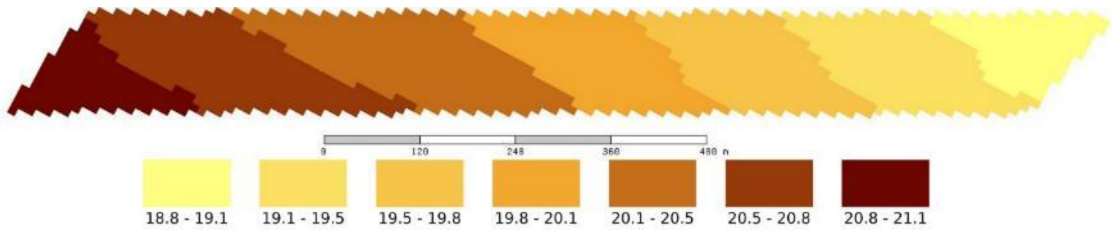


Figure 9-1 – plot of the elevations across block 3.

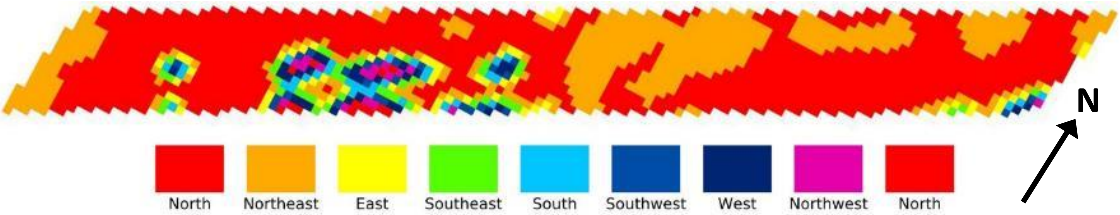
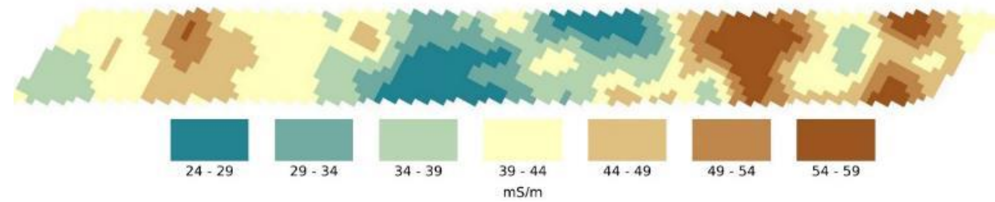


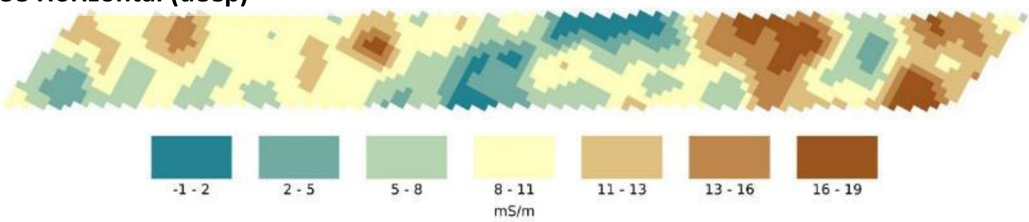
Figure 9-2 – plot of the slope aspect in block 3.

The EM38 device measures electric currents in the soil induced by an external magnetic field, the result is a measure of the apparent electrical conductivity or ECa. In the horizontal diapole mode ECa represents the top 0.75 m of the soil with the greatest sensitivity to the 0 – 0.3 m. The vertical diapole ECa reading represents the top 1.5 m of soil with the greatest sensitivity to 0.3 - 0.6 m depths. The ECa value is determined by a range of soil properties, but most significantly by the soil moisture content, clay content and type, porosity and pore water salinity. ECa increases with water content, clay content and salinity. The largest advantage of the EM38 is that it can be used to rapidly sample soil variability across large areas. The EM38 measurements for Block 3 at the Jordan site are shown in Figure 9-3 (a) and (b). In this case, the EM38 measurements were utilised to determine the best locations (Figure 9-3 c) for soil cores to be taken for chemical analysis.

(a) EM38 Horizontal (shallow)



(b) EM38 Horizontal (deep)



(c)

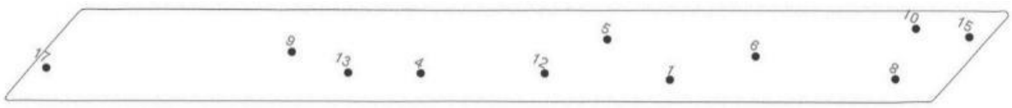


Figure 9-3 – (a) EM38 horizontal survey, (b) EM38 vertical survey and (c) soil core locations in block 3.

The soil cores did not highlight any significant spatial variation in soil chemistry across the field length and are not presented here. The soil tends to have an acidic surface layer (4.8 CaCl2) and a neutral pH in the subsoil (6.7 1:5 CaCl2). The bottom quarter of the field (where the EM38 is higher in Figure 9-3 a) appears to have a sodicity problem in the subsoil with high sodium and high ESP (ESP>10). Sodic soils have structural problems and are prone to waterlogging. These measurements were confirmed when installing the MultiFurrow probes, as this soil was observed to have drainage problems and maintained a high moisture content between irrigations.

The soil survey determined that the bulk of the soil across the block has a sandy clay topsoil and a loam subsoil. The spatial distribution of clay percentages is given in Figure 9-4.

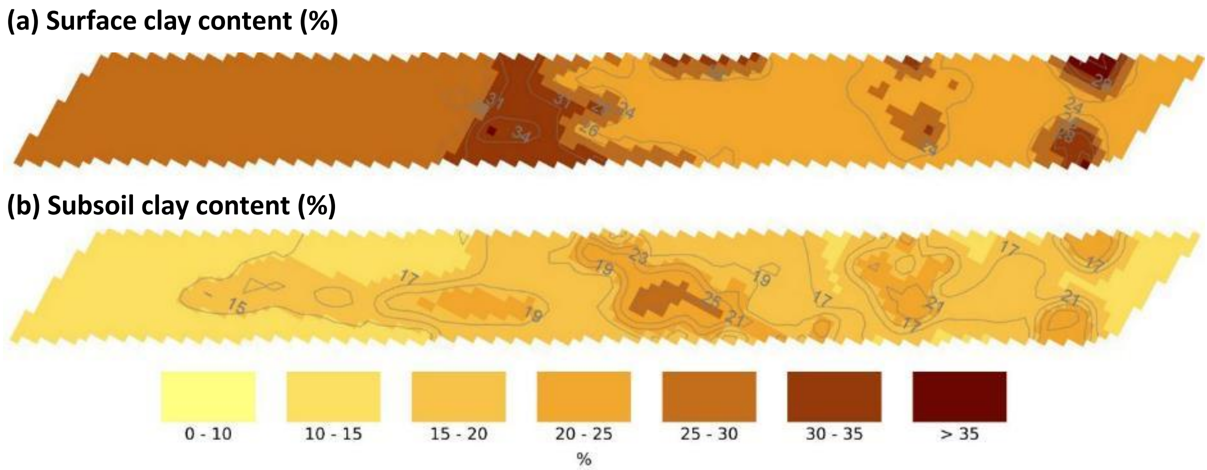


Figure 9-4 – Clay content percentage in the (a) surface and (b) subsurface layers in block 3.

One of the key soil properties for irrigation measurement is the plant available water content (PAW) which defines the amount of water which can be stored in the soil and can be accessed by plants. The average PAW across the block is 140 mm with values ranging from 122 mm to 177 mm (Figure 9-5) to 1.2 m.

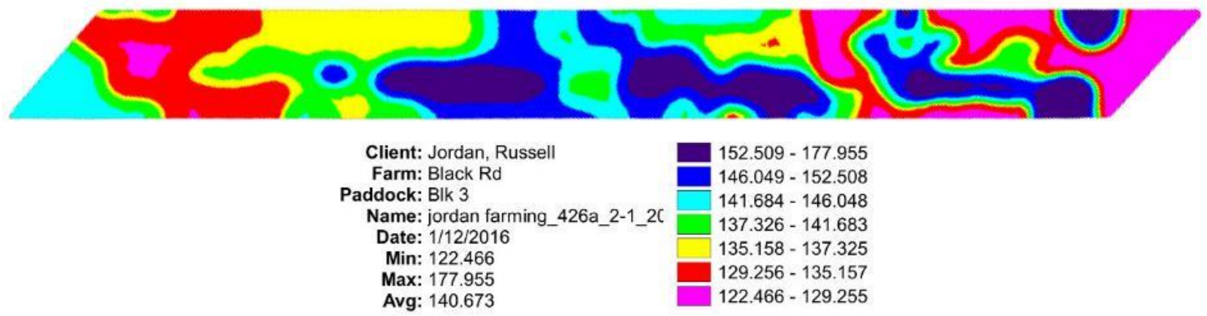


Figure 9-5 – Example map from soil survey - plant available water in mm (PAW) from 0 – 1.2 m.

9.5. Thermal imagery for advance detection

Thermal imagery has shown promise in small crops, such as cotton, to allow detection of the water advance as it moves down the field. The presence of water in the field has a cooling effect on both the soil and the plant, and can be easily observed by mounting a camera on a mast as shown in the example in Figure 9-7 (a). Sugarcane is a denser and taller crop than cotton, the soil is more likely to be shaded in sugarcane, and therefore would be cooler, and the potential change in temperature as water reaches the soil and plant is likely to be much lower than for cotton. The applicability of the thermal camera in sugarcane, for the purpose of detecting the advance front, required some preliminary testing. The camera selected for this testing is the ThermApp camera which is portable and can be connected to a smartphone.

The first test was conducted in a newly planted sugarcane field at the Linton site in 2015, during an IrriMATE evaluation prior to installation of the automation system. The measurements were collected from the bottom end of block 2 looking up the rows. This initial test was successful, as the advancing water front was clearly distinguishable from over 100 m away using a camera held at 1.6 m above the ground. Sample images from the daytime testing, are shown in Figure 9-6, where the dry soil exposed to the afternoon sun is at a temperature of above 45 degrees and the water is around 30 degrees. During the day, the dry soil exposed to sunlight was at a high temperature but the water maintained a lower temperature, furthermore moist soil was also observed with a lower temperature. At sunset, the temperature of the surface of the dry soil quickly dropped to ambient air temperature but the water temperature still maintained its original temperature, and so now the water was visible as the warmest part of the image and the dry soil was the cooler part of the image. This test proved that thermal imaging would work in ideal conditions, i.e. with no crop and dry soil but further work was required.

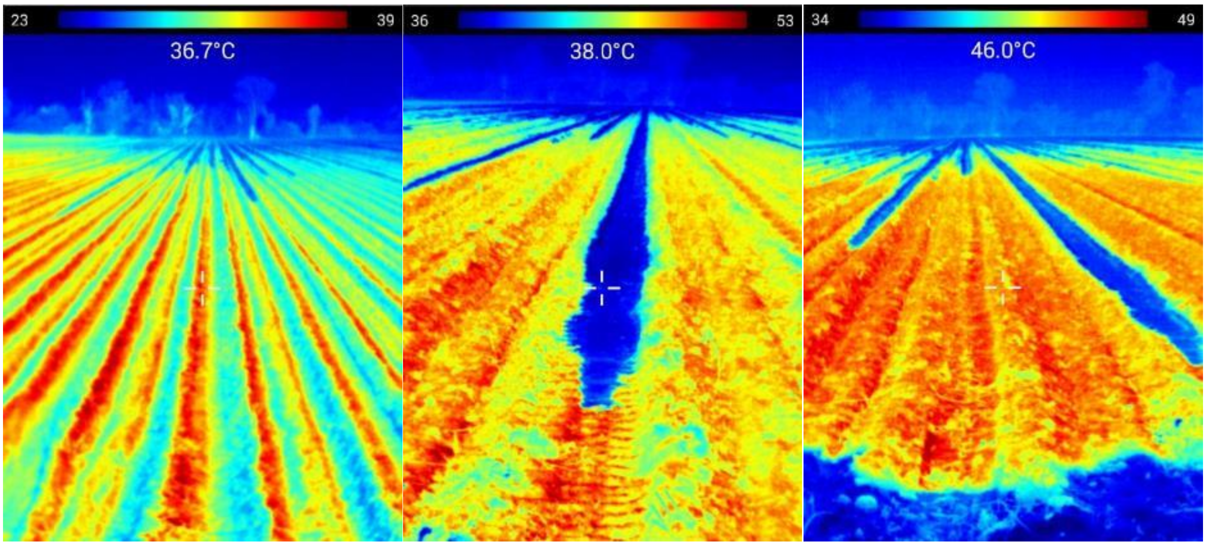


Figure 9-6 – Sample thermal image collected in daytime at bottom end of a newly irrigated plant block at the Linton site.

A second round of testing was completed in 2016, this time at the Jordan site. Here the camera was mounted on a temporary mast consisting of a 6 m length of PVC as shown in Figure 9-7 (b). This allowed testing at multiple locations within the paddock during a single irrigation event.

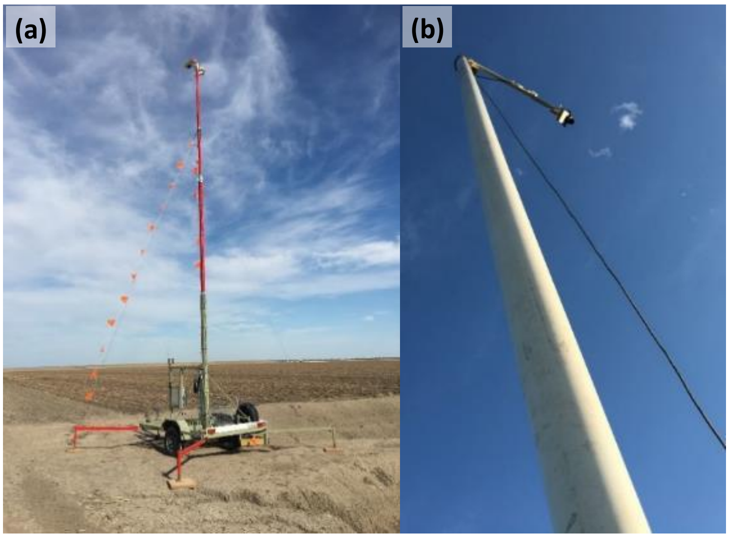


Figure 9-7 – (a) Thermal camera deployed at cotton field and (b) temporary 6 m mast in sugar cane.

This testing demonstrated that it was possible to see the water advance in the furrow even with only a small change in the temperature as shown in Figure 9-8 (a) where the maximum difference visible in this image is only 2 degrees. However, it was difficult to detect the water from one to two rows across as show in Figure 9-8 (b) where water is present in the two furrows to the left of centre. Further tests were conducted in this paddock, which contained sugarcane which was only 3-4 months old. Earlier tests in bare paddocks had been promising, but this failed test in young sugarcane meant that it was not worth proceeding any further with a mast mounted thermal camera in sugarcane for advance detection. However, the ability to see the water directly below the camera indicates that a drone mounted thermal camera would be able to detect the advance front.

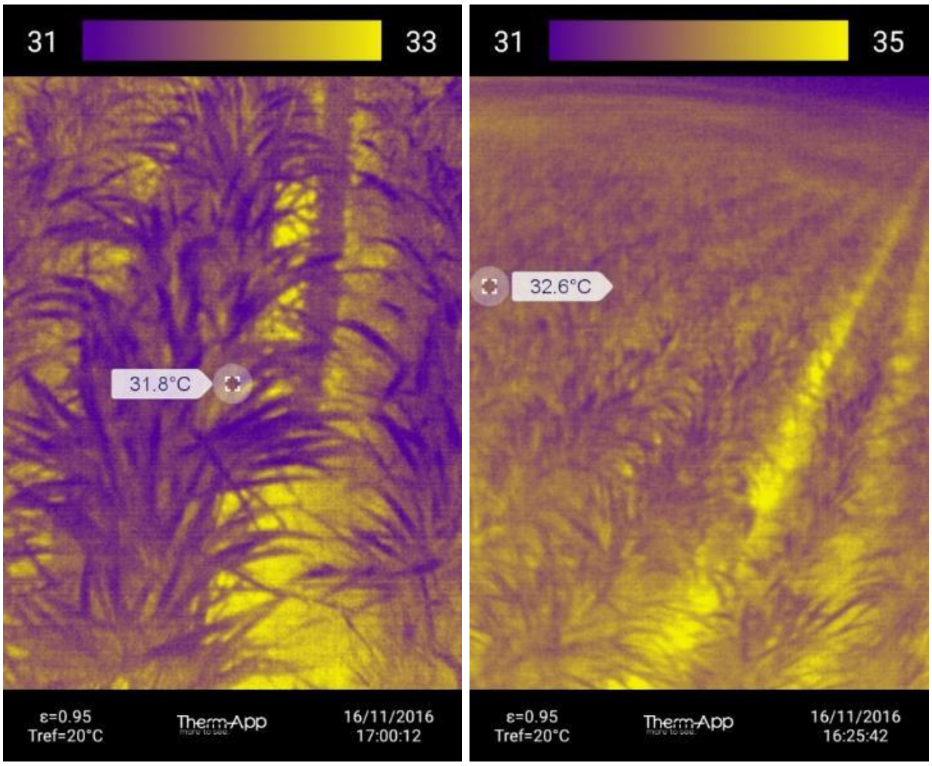


Figure 9-8 – Example thermal imagery (a) looking at the water from directly above and (b) looking at the water from two rows across.

It was concluded that the use of thermal cameras to detect water advance in sugarcane will be only possible through use of UAVs flying over the crop. The problem with UAVs is that they will only provide data for the limited time that they are in the air and at present use of UAV is restricted to those times at which the operator is on site. Hence UAVs are potentially useful for one off evaluations but are not yet practical for replacement of the infield buried advance sensors.

9.6. On Site Weather Data

9.6.1. Weather Station

A good understanding of the water balance is essential for scheduling of irrigations and evaluating seasonal performance of irrigation management. For this reason, as part of the Smarter Irrigation project, a weather station (Figure 9-9) was installed at the edge of the Jordan. This weather station includes:

- Temperature sensor in Stephenson Screen
- Humidity sensor
- Radiometer for solar radiation
- Anemometer - wind speed and direction
- Tipping bucket rain gauge

Figure 9-9 – Weather station installed at Jordan site.

The system was purchased through Environ Data and the measurements are automatically uploaded to the Weathermation Live website which allows graphing and storage of historical data as well as calculation of reference crop evapotranspiration. Access to this site has been given to Russell Jordan and the other members of the Steering Committee who are also interested in this device to monitor wind speed and direction for spraying.

For the WeatherMation username and password please contact Malcolm Gillies:
Malcolm.Gillies@usq.edu.au

This rainfall data was the data used in the IrrigWeb soil water balance modelling for the Jordan site.

9.6.2. Rain Gauges

Spatial variability of rainfall is a potential problem when trying to keep an accurate water balance of the field. Installation of a rain gauge at the site provides vastly improved information compared to the official BOM weather station which is in this case 30 km from the site. The rain gauge is one of the devices included in the weather station described above. In addition, the BPS has installed a rain gauge at the southern edge of block 1 as one of the soil moisture monitoring sites. This data is available at:http://www.cloudlink.net.au/Projects/Agritech/BPS/BPS3.html. Sugarcane growers are generally very interested in rainfall and are aware that rainfall is spatially varied but probably not aware of the magnitude of that variability.

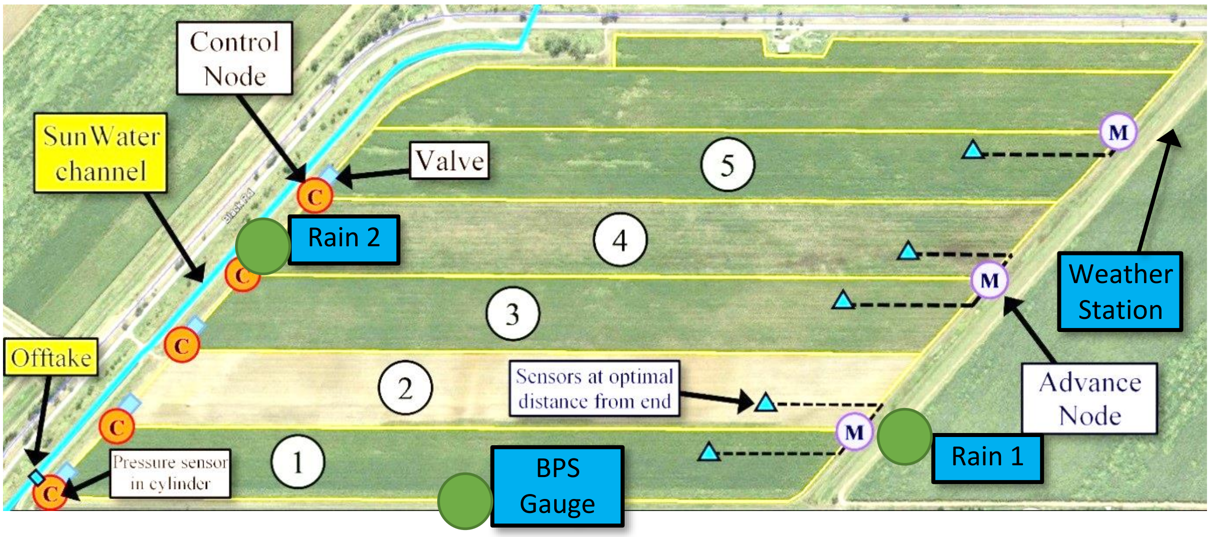


Figure 9-10 – Schematic of the field showing positions of the rain gauges.

Figure 9-11 – Davis rain gauge connected to WiSA radio at end of blocks 1&2.

Tipping rain gauges are relatively inexpensive ($100 - $150) and can be connected to any one of the WiSA radio nodes positioned at the valves or the advance detection points at the bottom of the field. To demonstrate this functionality and to improve the spatial resolution of the rainfall measurements, one rain gauge was installed at the end of block 1&2 and a second at valve 4 (as shown in Figure 9-10). A third rain gauge was installed at the Cadio Road pump station farm by the grower. All of these rain gauges are connected to the nearest WiSA radio node (Figure 9-11) and the rain intensity and cumulative depth are recorded at 5 minute intervals.

9.7. Future Activity planned for 2017-2018

There are a number of activities planned for the Jordan site for the current season, some of which have already commenced. The focus of the Smarter Irrigation project for this season is block 1, which was planted in early 2016 and is now in first ratoon.

One emerging soil moisture technology is the Acclima TDR315 soil moisture probe. TDR is more accurate than standard capacitance soil moisture probes and has a far larger soil sample size than any of the integrated, multi-depth, capacitance probes. Three of these probes have been deployed at 300mm, 600mm and 900m in block 1 and are connected to the nearest WiSA control radio.

Apart from water advance, thermal cameras should prove to be a useful tool to detect crop water stress. Generally speaking, crops attempt to maintain an optimal temperature and will struggle to do this when they become water stressed. When water stress commences, the canopy temperature will rise above this optimal level. A Flir Duo thermal camera has been mounted on a 7 m mast at the top of block 1 for this current season.

IrriMATE™ evaluations will be carried out in this field to allow the proper quantification of the irrigation performance and distribution of applied depths. Tests have already been performed in blocks 2 and 3 during the SRA project on both small and mature cane.

The MultiFurrow advance probes discussed in 6.5.6.4 will be deployed at a greater scale across 16 furrows in block 1, to obtain information on the variability of the advance, and to prove that the decisions made by the buried end of row trigger sensor are working correctly.

Finally, apart from the infield measurements, the project team will continue to use IrrigWeb to track the soil moisture balance and also investigate other tools such as IrriSat.

Note for Chapter 9:

Australian Government
Department of Agriculture and Water Resources

This project is supported by funding from the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit program.

10. COST BENEFIT ANALYSIS

10.1. Introduction

The purpose of this chapter is to conduct a cost benefit analysis on the current systems as installed at each of the three sites. Section 10.2 outlines the general assumptions which have been used to develop each case study while the specifics of each are detailed in subsequent subheadings for each of the sites.

10.2. General assumptions for the cost benefit analysis

The cost benefit analysis is driven by the system costs and the monetary savings or benefits which should be realised by the grower after installation of the automation system. The costs will vary between sites due to the hectares being automated and the relative size of each irrigation set. This section aims to outline some of the general costs which will apply to all scenarios. All costs are GST inclusive.

10.2.1. System Costs

10.2.1.1. Capital costs

The capital costs of each site are difficult to generalise, so they are presented in detail for each site. Below is a general description of each major component.

Base Station ($6,100 + additional cost per field node)
The base station comprises the radio base station ($3,000), personal computer ($1,200), external backup ($300) and software ($1,500) to control and monitor all field nodes. This investment is generally a once off cost across the entire farming enterprise providing that the fields are situated within radio reception of the base station or another field node. Nodes can generally transmit 5km line of sight.

Pump Site
Pump control involves installation of a radio pump control node at a cost of $3,000 plus electrician costs for connection to the pump and meter box. A single pump control node can control a number of pumps in a single location.

Block Control
Control of irrigation blocks is achieved through retrofitting a lever and linear actuator to the existing butterfly valve at a total cost of up to $900. These actuators are controlled using a WiSA radio node at a cost of $3000. Each of these control nodes can power up to 4 linear actuators providing they are in close proximity (i.e. 10m away) from the node. In practice, the system design means that either 1 or 2 valves are directly controlled by each node.

End of Row Sensors
The end of row sensor consists of a WiSA radio node ($3,000) connected to a device which can detect either the advancing water front or the depth of water in a drain. A range of sensors were tested during this project with values ranging from $200 to $800. A figure of $500 per sensor has been used

in this document. Each WiSA node can be connected to multiple sensors, the number of sensors per node is governed by the maximum cable length as defined by the particular sensor.

Commissioning
A final “commissioning” cost has been included in each scenario as a means to account for the labour associated with the professional installation of the automation hardware and configuration of the system. A figure of $5,000 has been adopted in each case study.

10.2.1.2. Annual costs

Unlike most automation systems there are no ongoing data costs which must be payed to the technology provider. The only ongoing costs will be to pay for an annual mobile data plan for those base stations which are not located in a home office with an existing internet connection.

10.2.1.3. Maintenance costs

It is assumed that the maintenance requirements over the first 7 years life of the system, as defined in 10.2.2, will be minimal. Maintenance/repairs costs after this time will increase but this analysis considers the first 7 years.

> *For example, probably the most likely component that will require replacement is the 12V battery. The expected life of these batteries is far greater than 12 months providing the system is charging properly but a complete replacement of this battery retails for only $30.*

A nominal figure of 1% of the capital value per year has been included in the analysis.

10.2.2. System Life

The financial analysis requires an estimation of the expected life of the system. All components when exposed to outdoor conditions and normal use will deteriorate slowly over time. After a given number of years each component may require servicing or replacement which will come at a cost. The system was designed with durability in mind, many of the components themselves have long expected operating lives.

The analysis below is based on the assumption that minimal servicing or component replacement will be required for the first 7 years after installation. This does not imply that the entire system will require replacement after 7 years, but selected components may require attention after this time. This 7 year life is used in the analysis below to define a realistic payback period. If we wish for the analysis to extend beyond 7 years we would need to consider an increased maintenance cost for each year past the 7 year milestone.

A 7 year system life will be assumed for the analysis, i.e. there will be no significant replacement of components required in the first 7 years.

10.2.3. Water and Energy Costs

There will be four potential cost savings in terms of water and energy possible through automation:

- Tariff saving - benefit in switching from a standard flat tariff to a time of use tariff
- Energy use saving due to reduced pumping time
- Water cost saving due to reduced irrigation duration
- Ability to temporarily trade unused water allocation as a result of reduced irrigation duration.

The ability to achieve each of these savings differs between the three case studies.

10.2.3.1. Electricity tariffs

Electricity costs associated with pumping can be an important economic component and must be considered in this analysis. At the current time, most irrigators are using one of the transitional tariffs, tariff 66, 65 or 62. These tariffs will be phased out no later than 30 Jun 2020. In parallel there are a second set of tariffs which should be considered, the small business tariffs 20, 21 and 22. These tariffs are available to customers using less than 100 MWhrs per annum.

The analysis will focus on the most commonly used tariffs 66, 65 and 62 but it must be realised that these will be phased out in less than 3 years from the present date. The details of the Ergon Energy/Origin Energy tariffs including GST as of 01/07/2017 are as follows:

Tariff 66: (flat tariff) – until 30/06/2020
Fixed Service Charge = $690.24/yr
Motor size pt 1 = $309.40/yr for first 7.5 kW
Motor size pt 2 = $124.03/yr per kW over 7.5 kW
Usage charge = 21.2718c per kWhr

Tariff 65: (negotiated 12 hour night period for off peak) – until 30/06/2020
Fixed Service Charge = $313.98/yr
Peak use charge = 40.5834c per kWhr
Off Peak use charge = 22.3531c per kWhr

Tariff 62: (Peak 7am to 9pm Mon-Fri) – until 30/06/2020
Fixed Service Charge = $314.98/yr
Peak use charge (first 10,000 kWhr/month) = 51.1676c per kWhr
Peak use charge (additional use) = 43.2696c per kWhr
Off Peak use charge = 18.0928c per kWhr

The three tariffs below are less commonly used. Tariff 20 and 22A will still be available after 30 June 2020 while tariff 22 small and large will be phased out in 2020 in a similar way as for the tariffs listed above. The main difference between the legacy tariffs and the new tariffs is that there is less incentive to move to off peak times because of the smaller price differential between the flat tariff 20 and the time of use tariff 22A.

Tariff 20: (flat tariff)
Fixed Service Charge = $483.80/yr
Usage charge = 30.490c per kWhr

Tariff 22A: (Peak Dec – Feb 10am-8pm weekdays)
Fixed Service Charge = $483.80/yr
Peak use charge = 62.915c per kWhr
Off Peak use charge = 26.258c per kWhr

Tariff 22 Small and Large: (Peak 7am-9pm Mon-Fri) – until 30/06/2020
Fixed Service Charge = $741.64/yr
Peak use charge = 54.802c per kWhr
Off Peak use charge = 19.297c per kWhr

Most growers without automation are currently using tariff 66 which offers the best rate for continuous 24hr use. Both Tariff 65 and Tariff 62 are classified as "time of use" meaning that there is a price differential between peak use and off peak use. Tariff 65 is based around a 12 hour off peak time each day which may be negotiated with the electricity provider but generally occurs overnight. Tariff 62 is based around an off peak time from 9pm to 7am each weekday and all weekend. The ability to exploit one of these time of use tariffs is reliant on the capacity of the system to operate with fewer than 24hrs per day. As a comparison, the number of hours available for pumping per week for these three tariffs is as follows:

- Tariff 66 = 168 hours per week
- Tariff 65 = 84 hours per week (50% of total)
- Tariff 62 = 98 hours per week (58.3% of total)

The ability to move to the time of use tariffs will depend on the design capacity of the irrigation system, i.e. the flowrates and area irrigated by each pump.

10.2.3.2. Water Costs

The water costs vary between the four water sources in the Burdekin. All costs are including GST.

Groundwater
In the LBW management area, groundwater is currently unmetered and growers pay a flat access rate per hectare, for this reason groundwater savings have not been factored into the analysis.

SunWater's Burdekin Haughton Scheme
The following costs are based on growers accessing water through SunWater channels, these costs vary for those accessing water through Glady's lagoon or in the Giru groundwater area. Parts A and C are charged based on the grower's full allocation (generally 8ML/ha) regardless of actual use. Parts B and D are paid based on the amount of water used. SunWater charges for the 2017-2018 water year, including GST, are:

Allocation charge (Part A)	= $12.10 per ML (payed on full allocation)
Channel Distribution (Part C)	= $26.31 per ML (payed on full allocation)
Open usage charge (Part B)	= $0.52 per ML (payed on water used)
Channel distribution (Part D)	= $28.18 per ML (payed on water used)

Farmers can purchase additional water on a temporary basis within the system either from SunWater or from another grower. The cost of this temporary trade is bargained on a case by case basis but is generally linked to the allocation charge (A + C) of $38.41 per ML. Farmers wishing to trade unwanted water can generally do so at a rate lower than the A+C charge as SunWater generally has unallocated water to sell in any given year. Anecdotal evidence suggests that farmers can expect to receive 90% of the SunWater price but to be conservative and/or to account for the difficulty in selling water this price will be reduced to 80% of the SunWater price.

Hence there will be three possible scenarios to reflect the impact of water savings:

A) Grower reduces water usage, but was already using less than the allocation (e.g. 8 ML/ha), and does not trade this saved water

Reduced usage = B+D	= $28.70 per ML
Total Saving	= $28.70 per ML

B) Grower reduces water usage, but was already using less than the allocation (e.g. 8 ML/ha) and does trade this saved water at 80% of SunWater price:

Total Saving = reduced usage + water sold
Reduced usage = B+D = $28.70 per ML
Water Sold = 80% of (A+C) = 80% of $38.41 per ML = $30.73 per ML

Total Saving = 28.70 + 30.73 = $59.43 per ML

C) Grower reduces water usage, but was already using more than the allocation (i.e. 8 ML/ha), and no longer needs to purchase additional water:

Total Saving = reduced usage + water not purchased
Reduced usage = B+D = $28.70 per ML
Water (not) purchased = 100% of (A+C) = $38.41 per ML
Total Saving = $28.70 + $38.41 = $67.11 per ML

SunWater Bulk Customer
These charges are applied to those growers who pump directly from the river and so do not use any of the scheme water infrastructure apart from the Burdekin Falls dam. The charges in 2017-2018, including GST, are as follows:

Allocation charge (Part A) = $12.10 per ML
Open usage charge (Part B) = $0.52 per ML (payed on water used)

Northern Division of Lower Burdekin Water (NLBW) charges, including GST:
Fixed area charge = $91.85 (grower) + $49.17 (miller) per ha per year
Open usage charge = $21.351 per ML within the nominal water entitlement
Excess usage charge = $16.214 per ML in addition to open usage charge
Total Saving = $21.351/ML within the nominal entitlement or $37.565/ML if above

Southern Division of Lower Burdekin Water (SLBW) charges, including GST:
Fixed area charge = $97.28 (grower) + $47.92 (miller) per ha per year
Open usage charge = $17.039 per ML within the nominal water entitlement
Excess usage charge = $16.214 per ML in addition to open usage charge
Total Saving = $17.039/ML within the nominal entitlement or $33.253/ML if above

Summary
The three growers in the project are classified as follows:

- Pozzebon = NLBW supplemented by groundwater
- Linton = SunWater Bulk
- Jordan = SunWater Burdekin Haughton

10.2.4. Costs associated with Irrigation Management

The largest potential benefit to most growers is the impact of automation on the time required for irrigation management or checking the progress of the irrigation. Successful management of furrow irrigation requires the grower to travel to the site and perform the tasks regularly throughout the irrigation season. The nature of irrigation in the Burdekin means that this labour is required at all times of the year, but at greatest intensity over the summer months. Much of the time these tasks must be performed at inconvenient times such as late at night or in the early hours of the morning. During peak season, the grower will be unable to travel away from the farm for any period of time which means that they will have limited time to spend with family and no chance of taking days or weekends off. The personal toll faced by growers, when their sleep is constantly interrupted by being forced to travel to the field to undertake irrigation tasks, is also considerable.

A cost benefit analysis cannot account for the full impact of the automation system on the grower's time and lifestyle. The cost benefit analysis will be limited to simply accounting for the time lost to the grower to perform these tasks.

10.2.4.1. Labour Cost

The precise cost of labour is difficult to establish for the farms considered. Larger corporate farms may have labour units dedicated to irrigation management tasks and will therefore be more readily able to quantify these costs. The scale of most sugarcane farms means that the owner operator or perhaps other family members will undertake these tasks and will not associate an hourly rate for this work.

The approach taken in this analysis is to assume a nominal hourly rate which reflects the value of the grower's time if the time saved was available to undertake other tasks. A figure of $30 per hour will be assumed throughout this document. Based on a 40 hour working week, 30 dollars per hour is equivalent to $1,200 per week or $62,400 per year.

10.2.4.2. Irrigation Management

The time consumed by undertaking irrigation tasks is difficult to quantify without taking detailed records of a grower's movements. Rather than attempting to capture these records for each grower, this document will rely on a single set of assumptions outlining the potential time saved by the automation.

It is proposed that each visit to the field will consume approximately 25 minutes of the grower's time. The tasks completed during each visit will involve some combination of the following activities:

- Stop current activity and locate vehicle
- Check bottom of field to determine if advance has reached end of field
- Open valve and/or start pump
- Check top of field including cups and fluming
- Close valve and/or stop pump
- Check channel screen
- Travel from vehicle back to previous activity

The result is that each visit will be associated with a cost of $12.50 in labour costs without including the time required to travel to the site.

There will be a minimum of one of these visits to the field for every irrigation event. Many growers will travel on average twice to the field during each irrigation. The assumption of the number of visits will be given for each case study.

10.2.4.3. Travel costs

The travel costs represent the vehicle costs and labour time which are involved in travelling to and from the farm to perform the irrigation visit. For most growers, there will be a trip associated with every visit to the field. The Linton case study is an exception to this where the number of trips is fewer than the number of visits because Aaron will tend to perform irrigation tasks when he is travelling to the farm for some other reason.

The growers may use a range of different vehicles in order to travel to the site. They may use a quad bike which will have a low fuel cost but high maintenance cost, a tractor with a high fuel cost and low maintenance cost, or a 4WD utility with mid-range fuel and maintenance costs. The analysis will assume that trips to the field involve driving a 4x4 diesel utility.

The RACQ releases figures which estimate the full cost of owning a range of vehicles based on 15,000 km per year. Most grower owned vehicles will travel a far greater annual mileage and therefore these figures have been adjusted for a distance of 30,000 km per year and fuel cost of $1.30/L.

Table 10-1 Estimated Vehicle Costs

Vehicle	List Price	On road	Fuel Cons.	Fuel	Tyres + Maint.	Running cost	Full Cost
			km/L	c/km	c/km	c/km	c/km
Toyota Hilux 2.8 D	$48,490	$51,246	0.086	11.7	9.27	20.97	53.92
Mazda BT50	$47,615	$51,130	0.092	11.96	9.23	21.19	54.75
Holden Colorado 2.8L D	$47,190	$53,045	0.09	11.18	7.75	18.93	50.42
Aaron Linton (2009 Colorado)			0.17	22.1	10.0	32.10	63.60[1]

[1] based on the fixed costs produced by RACQ

The fuel consumption estimated by Aaron Linton is much higher than stated by the manufacturer's data but this could be explained by the fact that manufacturer's data is based on highway cruising whereas the data provided by Aaron reflects the actual driving patterns of a farmer. The combined fuel, tyres and maintenance costs in the table above range between 18.93 to 32.10 cents per km. The full cost of the vehicle assuming 30,000km per year ranges between 50.42 to 63.60 cents per km. These figures are supported by the Australian Taxation Office which allows a rate of 66c per km in the 2016-2017 financial year for personal income tax deductions.

It is reasonable to assume that the farmer would not purchase this vehicle solely for irrigation management, therefore the running cost will be used rather than the full cost. The costs derived from RACQ data probably underestimate the fuel usage and wear and tear associated with driving on country roads and on farm. Therefore, the general running cost of 32 cents per km will be assumed throughout this report based on Aaron's data.

The labour cost associated with a trip to the field will be simply calculated based on the average travel speed of the trip. Each trip will involve a certain element of driving on public roads at higher speed and around the farm itself at a lower speed. The assumed speed will be given in each scenario.

10.2.5. Potential Yield Gains

Improvements to irrigation scheduling should result in small improvements to crop yield. The automation system will provide growers with a record of what has been applied in the past and give them the tool to enable them to apply the accurate amount of water at the right time, rather than the time that might suit labour availability. It is difficult to quantify what the potential yield increases might be but the IrrigWeb crop modelling examples in Chapter 8 provide a good indication. On the Linton site an irrigation schedule based on a 10 day cycle involved a 22 tonne yield penalty compared to the actual schedule (Section 8.2.5) and on the Jordan site IrrigWeb suggested that water stress in the middle of the season was resulting in yield decline of 19 tonnes (Section 8.3.2). The cost benefit analyses presented below assume modest 10 t/ha for the Linton site and 5 t/ha for the Pozzebon and Jordan sites.

This additional yield will not involve any extra cost apart from irrigation related expenses and harvesting cost. Based on recent sugar prices the net financial benefit of additional yield is close to $30 per tonne of sugarcane. This figure represents the mill price of sugarcane minus the harvesting cost.

Yield gains are not realised across the entire farm area each year. Sugarcane in the Burdekin, is normally replanted after 3 to 4 ratoons. After the final ratoon is harvested the land is either left fallow or planted to a rotation crop. Sugarcane is usually planted between February and April in the following year. This plant crop will not be harvested in the following harvest season but continue to grow and will be harvested in the following year. The result being that for a crop schedule of one plant and three ratoons, each field will be harvested 4 out of every 5 years. Hence for a 3 ratoon cycle a potential yield gain will be realised across 80% of the farming area. Similarly, for a 4 ratoon cycle the yield gain will be realised across 83.3% of the farming area. The short duration of the project means it is difficult to accurately quantify the potential yield increase and therefore scenarios will be presented for both no yield increase and with a small yield increase over 80% of the farm area.

10.2.6. Financial Analysis

The following aims to define the terms used and outline the calculation process of the financial analysis presented for each of the demonstration sites.

10.2.6.1. Discount Rate

The discount rate is a concept useful in predicting the current value of a future investment in infrastructure. The discount rate is meant to reflect the potential return on investment if this money is invested elsewhere. When applied to the Net Present Value analysis it is used to discount the value of a future benefit so that it can be related back to a present monetary value. The actual discount rate is a function of both interest rates and inflation rates.

For the purpose of this analysis a discount rate of 5% was chosen. A higher discount rate will cause money to devalue faster and mean that an investment becomes more difficult to return a positive result.

10.2.6.2. Net Present Value

The NPV or Net Present Value is a way to estimate the current net monetary value of a project accounting for the capital cost, net yearly benefit, investment life and potential return on investment if that money was invested elsewhere (discount rate).

The future value of a cost benefit is reduced by the annual discount rate to calculate the financial benefit in current monetary terms.

The NPV is calculated based on a discount rate of 5% over an equipment life of 7 years.

10.2.6.3. Payback Period

The payback period is defined as the period of time which it will take to recover the capital cost of the system through the potential benefits. The payback period can be calculated either without the discount rate or with the assumed discount rate. Neglecting the discount rate would reduce the payback period but possibly overestimate the benefits of the system. For this reason, the payback period in this document will include the discount rate of 5%.

10.2.6.4. Internal Rate of Return

The internal rate of return (IRR) is defined as the interest rate at which the net present value of cash flows (i.e. capital investment and projected savings) equal zero. The IRR determines the annual return on investment associated with the infrastructure.

10.3. Pozzebon Analysis

10.3.1. System Costs

The design for the Pozzebon site is detailed in section 6.2. In this case the automation system is installed over 8 irrigation blocks covering an area of 27 ha as shown in Figure 6-6. The full costings of the automation system at a commercial rate installed at site are given in Table 6-3. A summary of those costs is as follows:

Table 10-2 Summary of costs at Pozzebon site

	Cost	Per Ha
Base station	$7,700	
Pump site	$4,300	
Block control	$22,200	
Drainage sensor system	$20,500	
Commissioning	$5,000	
Full System	$59,700	$2,211
Full system without base station	$52,000	$1,926
Full system without drain sensors (base station included)	$39,200	$1,452

10.3.2. Pozzebon Assumptions

10.3.2.1. Pumps and Energy

Flow data is not available at this site so the quantification of water and energy use is based on a number of assumptions. The two main pumps at this site are as follows:

Pump 1 (6")

Motor = 3-phase Electric 11 kW running at 965 rpm
Pump = 200x150-250 KL ISO compact
Assumed flows based on pump curve between 40 to 60 L/s

Pump 2 (4")

Motor = 3-phase Electric 5.5 kW running at 1450 rpm
Pump = 200x150-250 Davey ISO spec
Assumed flows based on pump curve between 30 to 50 L/s

The data collected by the automation system does indicate the times when each pump was being operated but the complexity of the farm hydraulics and irrigation of other fields means that is difficult to precisely associate each block with one or both of the pumps. There are occasions when only pump

1 is being used and other occasions when both pumps are being operated. It is also possible that other pumps are also contributing to the water supply at the time of irrigation.

For simplicity, it was assumed that pump 1 is the only pump running during each of the irrigations in the automated blocks. The approximate flowrate of up to 60 L/s corresponds to individual furrow flows ranging from 0.770 L/s to 1.13 L/s which is within the expected range of furrow flowrates in order to successfully irrigate the field.

Pump 1 is connected to an 11 kW electric motor, it is likely that the actual power draw is below this value but without better information on the pump characteristic and system flow it will be assumed that the system is drawing 11 kW to achieve the 60 L/s during each irrigation event.

For the cost benefit analysis, it will be assumed that the pump(s) will be consuming a power of 11 kW whilst each block is being irrigated.

10.3.2.2. Water Supply

As previously mentioned, this property is irrigated with a combination of regulated channel/creek supply, shallow groundwater and on-farm recycle pits. For the purpose of this analysis it will be assumed that the primary water source is the regulated supply which is provided by the Northern Division of Lower Burdekin Water (LBW). All water pumped through the two pumps listed above is metered and charged by LBW. It will be assumed that any water saved through automation corresponds to the water price at the excess usage charge as defined in section 10.2.3.2.

For this analysis, it will be assumed that the additional water use saved with the automation is charged at the excess usage charge of $37.565 per ML (including GST).

10.3.2.3. Irrigation Management

Over 130 separate irrigation events have occurred within the automated blocks since the system was installed, the majority of which (over 113) occurring on the 6 blocks which were instrumented early in 2016. The measurements captured from the automation system suggest there are up to 20 irrigations per year on each block.

It was assumed that there are 18 irrigations per year on each block.

It is suggested that automation systems allow the grower to start and stop irrigation events at the correct time rather than at a time which is convenient for manual control. No data is available for these fields prior to the installation of the system but Denis has indicated that the system has improved his ability to schedule the irrigation events. It is also suggested that the use of end of row sensors enables the grower to determine when the irrigation has completed without having to visit the field. Ultimately these end of row or drainage sensors can be used to automatically switch between blocks or stop the irrigation.

While there is insufficient data available to comment on the water use efficiency of any individual events it is clear that the system has improved the ability of the grower to manage the system. The reduction of runoff losses was not a priority at this site as the tail-water from all automated blocks can be captured in recycling ponds. However, a reduction in tail-water will result in savings in terms of pumping and water charges.

For this site, drainage sensors were installed a number of months after the valve controls. Therefore, an analysis of the irrigation durations over time should provide some indication of how the management has evolved as the drain sensors were installed and after Denis gained confidence in the ability of these sensors to indicate when the irrigation was completed.

It might be expected that if the automation system has resulted in efficiency improvements at this site then there should be a general decrease in the irrigation durations. It was difficult to make conclusions based on individual events as the irrigation durations vary from event to event. Instead the irrigation events from blocks 1 to 6 were split into two groups, one containing the events prior to the end of December 2016 and the other for all events within 2017. The result was two approximately equal groups which can be used to illustrate trends in management.

In every one of the 6 blocks, there is a reduction in the median irrigation duration in 2017 compared to 2016. This reduction varied between 2.2 hours to 5 hours per event between individual blocks. Combining all 115 events the median event duration reduced from 876 minutes (14.6 hrs) in 2016 down to 673 minutes (11.2 hrs) in 2017 which equates to a median reduction of 3.4 hours

The results are similar for individual blocks, for example in Block 1 there have been 22 events between April 2016 and July 2017. The median event duration in 2016 was 851 minutes (14.2 hrs) while in 2017 it was 720 minutes (12 hours)

It will be assumed that the automation system enables a conservative reduction of 2 hrs per irrigation event.

10.3.2.4. Labour and Travel associated with Management

For Denis, it will be assumed that there will be 2 visits on average to the field for each irrigation event.

Denis lives on site, so distances travelled will be minimal; some example distances from his home are as follows:

- Return from the home to the main pumps 2.2km
- Return trip around the circumference of the 8 automated blocks 3.0km
- Return trip to check completion, top end to change valves and pump 3.9km

A nominal distance of 3 km will be assumed for each trip to the field at a speed of 15 km/hr, vehicle costs will be 32c/km as defined in 10.2.4.3. Each visit will consume 25 minutes of his time as defined in 10.2.4.2 in addition to the travel time.

10.3.2.5. Potential yield gain

In the absence of infield measurements, it is difficult to make any conclusions on the efficiency or the adequacy of the irrigation events. Based on the assumed flows and measured irrigation schedule there is no evidence that the crop is being significantly under irrigated so potential yield gains will be minimal with automation.

Two scenarios will be used for the cost benefit analysis:

- No yield gain
- 5 tonne cane/ha yield gain which represents a 2-3% yield increase which could be easily achieved if the automation permits better timing of irrigation events.

10.3.3. Breakdown of potential benefits for Pozzebon

The assumptions above allow us to predict potential benefits associated with adoption of the automation system. These will be used to generate the scenarios in the following section.

Number of events:

8 blocks x 18 events per year = 144 events per year

Vehicle costs

144 events x 2 trips per event @ 3km = 864 km per year

Fuel and Maintenance cost @ 32c per km = $276.48

Potential labour savings:

144 events x 2 visits @ 25 minutes for each visit = 120 hours

120 hours @ $30 per hour = $3,600.00

Travel time, 864km @ 15km/hr = 54.6 hours

57.6 hours @ $30 per hour = $1,728.00

Total Labour saving = $5,328.00

Potential power saving:

Assuming 2 hour reduction in pumping per event:

144 events @ 2 hours @ 11kW on Tariff 66 = $673.89

Potential water saving:

Assuming 2 hour reduction in pumping per event:

144 events @ 2 hours @ 60 L/s @ $21.351/ML = $1,328.20 (within entitlement)

OR

144 events @ 2 hours @ 60 L/s @ $37.565/ML = $2,336.84 (above entitlement)

The analysis assumes that the water saved is within the excess usage charge.

Benefit of potential yield increase:

5 t/ha over 80% of 27 ha = 108 tonnes

108 t @ $30/tonne = $3,240

10.3.4. Cost Benefit Results for Current system at Pozzebon site

10.3.4.1. NPV analysis

Five different scenarios were chosen to conduct the cost benefit analysis. The calculations have used a discount rate of 5% per annum and have assumed a 7 year timeframe for NPV and IRR. The scenarios tested are as follows:

1. Complete system with no change to management or crop yield
2. Complete system with a 2 hour reduction in water use, no change in crop yield
3. Complete system with both a 2 hour reduction in water use and 5 t/ha yield increase
4. System without base station, no change in water use and a 5 t/ha yield increase
5. System without base station, 2 hour reduction in water use and a 5 t/ha yield increase

Scenarios 4 and 5 are the most representative of the system installed during the project because this farm already had the base station and associated hardware and software installed on a PC in the home office.

Scenario 1 – Complete system with no change to management

Costs: Complete system including base station & pump control
Benefits: Labour, travel time, vehicle costs
Water/Energy: No change
Yield: No change

Capital cost	$59,700.00		NPV (7 year timeframe)	- $30,725
Annual Cost	$0.00		Payback period	18.54 years
Maintenance Cost	$597.00		IRR (7 year timeframe)	- 11.8 %
Gross Annual Benefit	$5,604.48			
Net Annual Benefit	$5,007.48		Capital cost over 7 years	$8,529

Scenario 2 – Complete system with 2 hour reduction in water use

Costs: Complete system including base station & pump control
Benefits: Labour, travel time, vehicle costs
Water/Energy: Reduction of 2 hours per irrigation
Yield: No change

Capital cost	$59,700.00		NPV (7 year timeframe)	- $13,304
Annual Cost	$0.00		Payback period	9.55 years
Maintenance Cost	$597.00		IRR (7 year timeframe)	- 1.5 %
Gross Annual Benefit	$8,615.21			
Net Annual Benefit	$8,018.21		Capital cost over 7 years	$8,529

Scenario 3 – Complete system with 2 hour reduction in water use and 5t/ha yield increase

Costs:	Complete system including base station & pump control
Benefits:	Labour, travel time, vehicle costs
Water/Energy:	Reduction of 2 hours per irrigation
Yield:	5 t/ha increase (on 80% of area)

Capital cost	$59,700.00		NPV (7 year timeframe)	+ $5,444
Annual Cost	$0.00		Payback period	6.32 years
Maintenance Cost	$597.00		IRR (7 year timeframe)	+ 7.5 %
Gross Annual Benefit	$11,855.21			
Net Annual Benefit	$11,258.21		Capital cost over 7 years	$8,529

Scenario 4 – Actual case, complete system but no base station

Costs:	Complete system without base station
Benefits:	Labour, travel time, vehicle costs
Water/Energy:	No change
Yield:	5 t/ha increase (on 80% of area)

Capital cost	$52,000.00		NPV (7 year timeframe)	- $3,831
Annual Cost	$0.00		Payback period	7.68 years
Maintenance Cost	$520.00		IRR (7 year timeframe)	+ 2.9 %
Gross Annual Benefit	$8,844.48			
Net Annual Benefit	$8,324.48		Capital cost over 7 years	$7,429

Scenario 5 – Actual case, complete system but no base station

Costs:	Complete system without base station
Benefits:	Labour, travel time, vehicle costs
Water/Energy:	Reduction of 2 hours per irrigation
Yield:	5 t/ha increase (on 80% of area)

Capital cost	$52,000.00		NPV (7 year timeframe)	+ $13,590
Annual Cost	$0.00		Payback period	5.35 years
Maintenance Cost	$520.00		IRR (7 year timeframe)	+ 11.8 %
Gross Annual Benefit	$11,855.21			
Net Annual Benefit	$11,335.21		Capital cost over 7 years	$7,429

The net positive value (NPV) in scenarios 1, 2 and 4 is negative meaning that the estimated benefits are not sufficient to recover the initial capital cost within the specified 7 year timeframe. Conversely, scenarios 3 and 5 have a positive NPV indicating that the investment is recovered before the end of 7 years. Both the positive scenarios assume a small yield increase and reduction in pumping time which indicates that both are required for a favourable outcome. Scenario 5 has the highest net benefit with a payback period of 5.35 years.

The Pozzebon site has the highest capital cost per unit area of the three sites which is evident in the poor results for the cost benefit analysis. While the benefits are significant and of simular magnitude to the other two sites, they are not sufficient to overcome the higher capital costs per hectare at this site.

10.3.4.2. Benefits Breakdown

Scenario 5 is chosen to illustrate the potential benefits of automation at this site. The results from this scenario will be used to demonstrate the relative contributions to the annual benefits associated with the automation. Figure 10-1 contains a summary of those benefits expressed in terms of dollars per hectare.

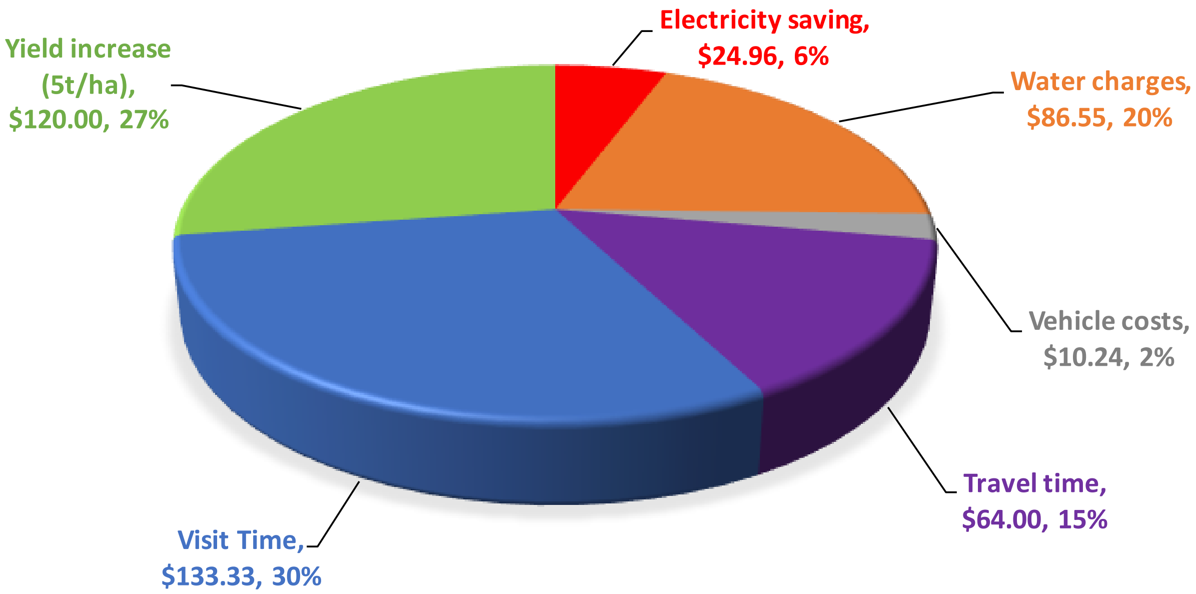


Figure 10-1 – Breakdown of benefits from Pozzebon site (current) per hectare for scenario 5

The electricity saving and water charges represent the potential cost reduction if each irrigation duration was shortened by 2 hours, when combined these provide a benefit of $111/ha per year. Water and energy charges are directly linked to electricity prices which can be expected to increase over the 7 year timespan but this was not included in the analysis. The vehicle costs in this case are minimal as the estimated travel distance is only 864 km/year and costed at a fuel and maintenance rate of 32 cents per km.

The largest benefits for this site are associated with the labour component which represents $197/ha per year. This benefit is comprised of the time required to drive the 864 km ($64) and the time associated with each visit ($133).

The other component of the benefits is that of the potential yield increase. An increase of 5 t/ha over 80% of the automated area equates to 108 tonnes per year which is a conservative estimate if the automation does in fact have a positive impact on the irrigation scheduling.

10.3.4.3. Sensitivity to Yield

Out of all benefits, the yield increase is the most difficult to estimate reliably as it is influenced by many factors independent of the automation system. The sensitivity of the benefits to this assumed yield benefit was analysed by selecting three of the above scenarios and varying the yield gain from 0 to 20 t/ha. All other factors were held consistent with the results above including the discount rate of 5%. The three scenarios selected were:

- Scenario 1 – Full system cost, with vehicle and labour savings
- Scenario 3 – Full system cost, with vehicle, labour, energy and water savings
- Scenario 5 – System cost without base station, and with vehicle, labour, energy and water savings

Figure 10-2 summarises the findings of this sensitivity analysis in terms of payback period and clearly shows the impact of yield.

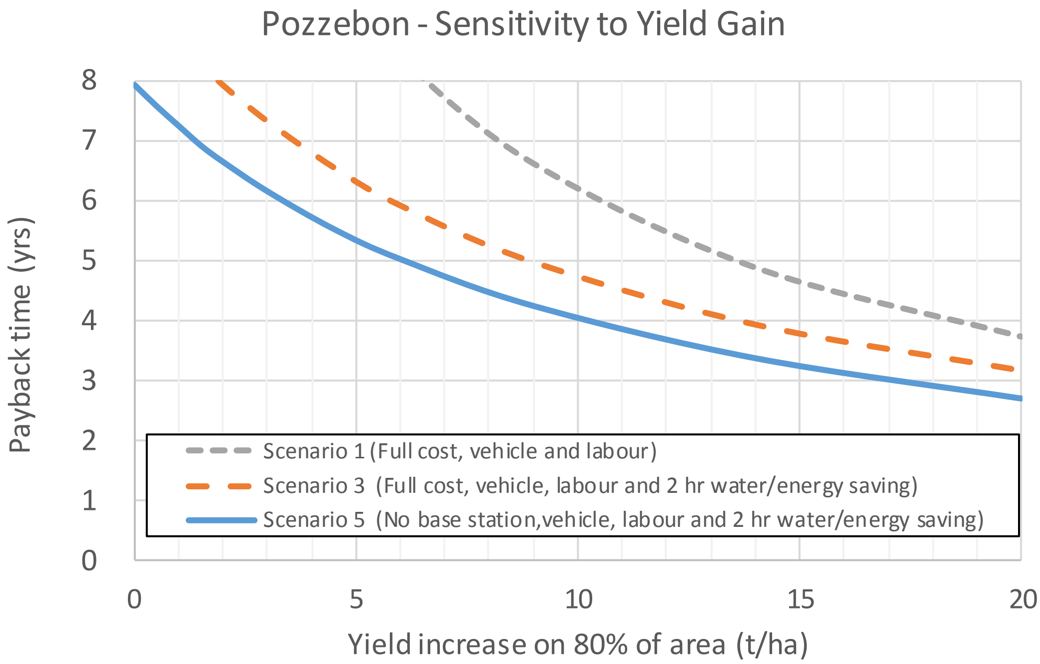


Figure 10-2 – Sensitivity of payback period to yield increase for Pozzebon (current) site

When considering the full cost and no water or energy saving (scenario 1), the investment will require a yield increase of 8 t/ha in order to recover the capital cost within 7 years. With a 2 hour reduction in irrigation duration per event this drops to 4t/ha of increased yield. The lack of volumetric measurements at this site prevents any conclusion on how difficult it might be to achieve these yield benefits. The one simple conclusion from Figure 10-2 is that it is difficult to justify the investment at this site based on financial benefits alone if there is no increase in yield.

10.3.5. Scenario Results for Entire Farm

10.3.5.1. Design of Entire Farm

The costs above represent a 27 hectare portion of the Pozzebon farm which represents less than 1/3 of the farm area. The cost of this system, as detailed in Table 6-3 at $2,211 per ha, is higher than that of the other farms but it is expected that this cost will be reduced if the system is deployed over the remainder of the farm. To the north of block 8 there is an additional 60 hectares spread across 16 irrigation blocks as shown in Figure 6-5.

A second Pozzebon design is proposed, the “Pozzebon Entire Farm”, which contains 24 blocks covering a total of 87 ha. A rough system design for the new 60 ha is proposed by placing valves at existing risers and placing three drain probes at crucial parts of the drainage network as shown in Figure 10-3. This new development would utilise the same base station as the current 27 ha site with a small additional software licencing fee to cover the additional radio nodes. Seven new control nodes are required, each one connected to two valves (Figure 10-3) and one valve is connected to the existing pump control unit. The current system controls two pumps at a single location using one pump control node. For the complete system, it is proposed that an additional 3 pump control nodes are required for groundwater and recycle pit pumps. A minimum of three drainage nodes and probes are required to monitor the new area. The number of drainage nodes in the current 27 ha could be reduced from 5 to 3 by trenching the cables from the existing drain sensors along the headland which brings the total number of drain nodes to 6 with 9 drain probes. This system would involve a higher commissioning cost than the original 27 ha which has been increased from $5,000 to $10,000.

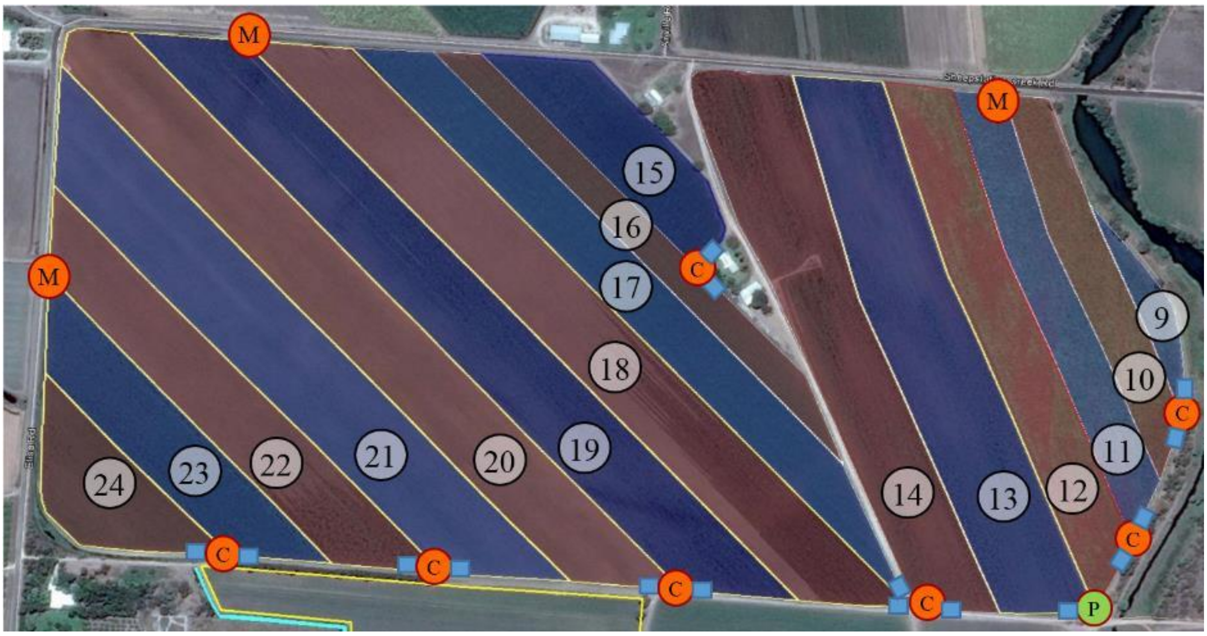


Figure 10-3 – Satellite image of area north of block 8 at Pozzebon site

A new cost breakdown for the entire 87 ha farm is given in Table 10-3. The total cost of the system has increased from $59,700 to $120,300 but the area automated has increased from 27 ha to 87 hectares. Consequently, the cost per unit area has dropped significantly from $2,211 to $1,383, a 37% reduction from the current price. This should make the system far easier to justify considering the potential benefits detailed above.

Given that the 27 hectare system is already installed it is more reasonable to consider the costs in two parts. The original cost of $2,211 per hectare represents this current installation. Further investment in the 60 ha expansion costs $1,010 per hectare over that new area which makes this expansion more attractive than considering the full system cost.

Table 10-3 Cost breakdown of Pozzebon Entire Farm

Base Station	(costs are once off for farm)	Price	Qty	Total (inc GST)
Base station	complete with radio and aerial	3,000	1	3,000
Setup	software, bitmaps, dongle	1,500	1	1,500
Setup	licence ports	80	40	3,200
Computer		1,200	1	1,200
External HDD + UPS	backup	300	1	300
Internet		100	1	100
				$9,300
Pump Site	(control of both main pumps)			
Pump controller	24 output	3,000	4	12,000
Installation	electrician	500	4	2,000
Pressure transducer	4m submersible	800	2	1600
Pressure transducer	4m external	400	2	800
				$16,400
Block Control				
Actuator control node	controls 2 actuators	3,000	12	36,000
LINAK Actuator	LINAK LA-35	500	24	12,000
Bracket	Green's valve	300	24	7,200
Bracket fitting	labour - COAR	100	24	2,400
				$57,600
End of Row Sensors				
Advance node	Can connect to any number of probes	3,000	6	18,000
Drainage Probes	SM probes	500	9	4,500
Install	Correct positioning, configuration	500	9	4,500
				$27,000
Commissioning	physical installation of the base station, field radios, and checking			**$10,000**
		Per ha		
Total (Entire system)		$1,383		**$120,300**
Without base station (i.e. another farm in radio coverage)		$1,276		**$111,000**
Entire system without drainage sensors (control only)		$1,072		**$93,300**
Extra cost in addition to current system		$1,010		**$60,600**

10.3.5.2. Benefits for entire farm

The potential benefit across the entire 87 hectares differs slightly to that for the current 27 hectares. With the exception of the yield, most of the benefits are accrued on a per block basis and the average block size increases from 3.375 ha to 3.625 ha. Hence there is a slight reduction in benefits per hectare when considering the whole 87 hectares.

The same logic outlined in 10.3.3 can be repeated for 24 blocks over 87 hectares. The breakdown is as follows:

Number of events:

24 blocks x 18 events per year = 432 events per year

Vehicle costs

432 events x 2 trips per event @ 3km = 2,592 km per year

Fuel and Maintenance cost @ 32c per km = $829.44

Potential labour savings:

432 events x 2 visits @ 25 minutes for each visit = 360 hours

360 hours @ $30 per hour = $10,800

Travel time, 2,592km @ 15km/hr = 172.8 hours

172.8 hours @ $30 per hour = $5,184

Total Labour saving = $15,984.00

Potential power saving:

Assuming 2 hour reduction in pumping per event:

432 events @ 2 hours @ 11kW on Tariff 66 = $2,021.67

Potential water saving:

Assuming 2 hour reduction in pumping per event:

432 events @ 2 hours @ 60 L/s @ $21.351/ML = $3,984.61 (within entitlement)

OR

432 events @ 2 hours @ 60 L/s @ $37.565/ML = $7,010.53 (above entitlement)

The analysis assumes that the water saved is within the excess usage charge

Benefit of potential yield increase:

5 t/Ha over 80% of 87 ha = 348 tonnes

348 t @ $30/tonne = $10,440

10.3.5.3. Cost Benefit analysis for Entire Farm

The same 5 scenarios listed above were repeated for the entire 87 hectares using the new costs and the potential benefits above. The same 5% discount rate and 7 year period was adopted in this analysis. A summary of this analysis is given in Table 10-4 showing the clear difference in results between the current 27 hectares and the entire 87 hectares.

There is a slight drop in the net benefit per hectare as discussed previously because of the larger average block size but this is completely overcome by the smaller capital cost of the system. This time, only one of the 5 scenarios does not recoup the capital costs within the 7 year time frame of the analysis. This indicates that the labour savings and travel cost savings alone are not sufficient to justify the system. In general, the capital expense in modernising the entire farm will be recouped in between half to 2/3 of the time than compared to the current 27 hectares. Scenario 3 which includes the full cost and all of the potential benefits can pay back the system in 3.9 years which is quite a decrease compared to the 6.3 years for the current 27 hectares.

Table 10-4 – Summary results for Pozzebon farm for current area and entire farm

	Scenario	1	2	3	4	5
		Full cost, no yield increase, no reduction in water	Full cost, no yield increase, 2 hour pumping reduction	Full cost, +5 t/ha, 2 hour pumping reduction	No base station, +5 t/ha, no reduction in water	No base station, +5 t/ha, 2 hour pumping reduction
Current area (27 ha)	Capital ($/ha)	$2,211	$2,211	$2,211	$1,926	$1,926
	Ann. Net Benefit ($/ha)	$185	$297	$417	$308	$420
	IRR	-11.8%	-1.5%	7.5%	2.9%	11.8%
	Payback period (yrs)	18.5	9.6	6.3	7.7	5.4
Entire farm (87 ha)	Capital ($/ha)	$1,383	$1,383	$1,383	$1,276	$1,276
	Ann. Net Benefit ($/ha)	$179	$283	$403	$300	$404
	IRR	-2.3%	9.9%	21.9%	14.3%	25.1%
	Payback period (yrs)	10	5.8	3.9	4.9	3.5

The same sensitivity analysis to yield was repeated for the entire farm (Figure 10-4). Here scenario 3, representing the full cost can be recovered in just over 5 years with no yield gain but can be recovered in 2 years if a 15 tonne increase is possible. Previously, for scenario 1 a yield increase of 8 t/ha was required to yield a positive benefit in 7 years, now that yield has been decreased to 4 t/ha.

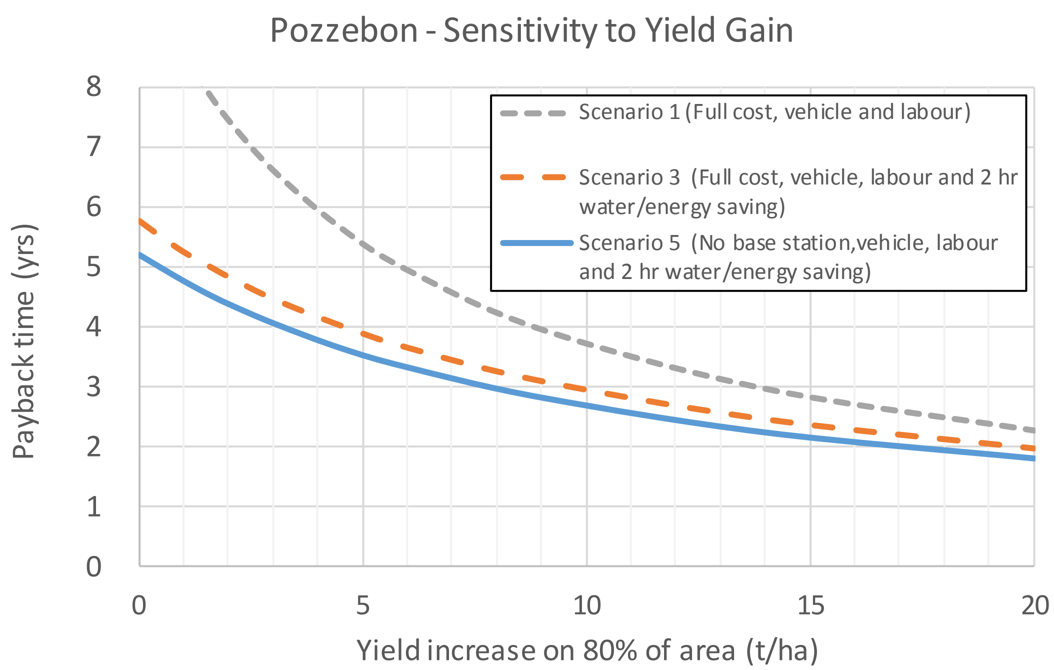


Figure 10-4 – Sensitivity of payback period to yield increase for Pozzebon (entire farm) site

10.4. Linton Analysis

10.4.1. System Costs

The design for the Linton site is detailed in section 6.4. In this case the automation system is installed over 11 irrigation blocks covering an area of 53 ha as shown in Figure 6-17. The full costings of the automation system at a commercial rate installed at site are given in Table 6-5. A summary of those costs is as follows:

Table 10-5 Summary of costs at Linton site

	Cost	Per Ha
Base station	$7,700	
Pump sites	$7,800	
Flowmeters	$11,465	
Block control	$27,900	
Drainage sensor system	$8,500	
Commissioning	$5,000	
Full System	$68,365	$1,290
Full system without base station	$60,665	$1,145
Full system without drain sensors *(base station included)*	$59,865	$1,130
Entire system with no flowmeters and ½ of base station *(because base station also serves the drip)*	$53,050	$1,001

10.4.2. Linton Assumptions

10.4.2.1. Pumps and Energy

There are two pumps at this site connected to the furrow irrigated blocks, pump 1 connected to blocks 1 & 2, pump 2 connected to blocks 3 to 11. The details of the pumps are as follows:

Pump 1 (blocks 1 & 2):

Motor = 3-phase Electric 30 hp (22.4 kW) running at 1470 rpm
Pump = 150x124-250 Starline Southern Cross (pump curve provided) – MGG54C-F
Flow = 75.31 L/s (range 68.9 L/s – 77.3 L/s)
TDH = 21.0 (estimated from pump curve and known pipe dimensions and static lift)
Pump efficiency = 83% (from pump curve)
Motor efficiency = 90% (assumed)

The motor input power was calculated for each event individually from the measured flow in each event. The resulting average power draw equates to 21.02 kW which matches well with the 22.4 kW stated on the motor.

Measurements from 01/07/1016 – 01/07/2017 (1 complete year)

Pumping time = 368.84 hours
Volume = 99,861 kL (note that a large proportion of this water is captured in the recycle pit)
Energy = 7,741.84 kWhrs

Cost on Tariff 66 = $4,494.59 ($45.01/ML)
Cost on Tariff 65 = $2,043.72 ($20.47/ML)
Cost on Tariff 62 = $1,715.70 ($17.18/ML)

Pump 2 (blocks 3,4,5,6,7,8,9,10 & 11):

Motor = 3-phase Electric 30hp (22kW) motor at 1470 rpm
Pump = SNB6, 359 impeller pump (manufactured 1978)
Flow = 59.79 L/s (range 52.6 L/s – 65.3 L/s)
TDH = 21.3 (estimated from known pipe dimensions and static lift)
Pump efficiency = 67.19% (Based on pump perf. measurements conducted in 2014)
Motor efficiency = 90% (assumed)

The motor input power was calculated for each event individually from the measured flow in each event. The resulting average power draw equates to 20.65 kW which matches well with the 22.4 kW stated on the motor.

Measurements from 01/07/1016 – 01/07/2017 (1 complete year)

Pumping time = 1425.94 hours
Volume = 367,338 kL (note that a large proportion of this water is captured in the recycle pit)
Energy = 35,231.85 kWhrs

Cost on Tariff 66	= $10,342.21	($28.15/ML)
Cost on Tariff 65	= $8,188.59	($22.29/ML)
Cost on Tariff 62	= $6,689.41	($18.21/ML)

Combined Pump water and energy use extrapolated to 53 ha:

These figures represent the pumped volume, energy use, and power costs assuming that all 53 hectares was irrigated according to the management observed in the 2016-2017 financial year.

Volume = 486,099 kL (note that a large proportion of this water is captured in the recycle pit)
Energy = 44,712.145 kWhrs

Cost on Tariff 66	= $15,206.59	($31.28/ML)
Cost on Tariff 65	= $10,620.91	($21.85/ML)
Cost on Tariff 62	= $8,719.64	($17.94/ML)

For this analysis, it is assumed that the pump energy use in the 2016 to 2017 financial year is representative of the normal energy use. It will also be assumed that under manual control the farmer will be forced to use tariff 66 but with automation can utilise tariff 62.

10.4.2.2. Water Supply

At this site, the water is pumped directly from the river under a bulk water application from SunWater. The GST inclusive charges in 2017-2018 are

Allocation charge - $12.10 per ML
Open usage charge - $0.52 per ML

With the low access cost for this water there is limited benefit in including any impacts of altered water use in the following analysis but they have been included for consistency.

A water use charge of $0.52 per ML was assumed for any water saving.

10.4.2.3. Irrigation Management

There have been over 400 individual irrigation events at this site since the installation of the furrow irrigation system in January 2016. The analysis here will focus on the 12 months between the 01/07/2016 and 01/07/2017.

For pump 1 there was a total of 36 events over this year, or an average of 18 events per block. For pump 2 there was a total of 266 events or an average of 29.6 events per block.

The high number of events for pump 2 is a result of the surging which was practiced on blocks 3 and 4 and which were responsible for 68 and 64 irrigations in that year long period alone. This surging would not occur under manual measurement and therefore a more conservative figure of 20 irrigation events per block was assumed across all irrigation blocks.

It was assumed that there are 20 irrigations per year on each block for pumps 1 and 2.

It is suggested that automation systems allow the grower to start and stop irrigation events at the correct time rather than at a time which is convenient for manual control. It is also suggested that the use of end of row sensors enables the grower to determine when the irrigation has completed without having to visit the field. Ultimately these end of row or drainage sensors can be used to automatically switch between blocks or stop the irrigation. Aaron Linton has altered the irrigation management significantly now that the entire farm is automated. Irrigations now occur almost exclusively during the off-peak power periods with a typical maximum duration of 10 hours. This is a contrast to typical grower management where irrigation durations could be significantly longer as it would require the grower to visit the site at the start and end of each event.

The cost benefit analysis requires an assumption on the impact of automation on the irrigation schedule. The analysis below adopts the simplistic assumption that if the system was to be manually controlled there would be an increase in pump run time of 20% over the measured durations. The majority of irrigations at this site are conducted on a 10 hour shift since adoption of automation. A 20% over-irrigation corresponds to a 12 hour irrigation shift which is more practical for manual control than compared to a 10 hour shift.

It was assumed that manual control would result in a general increase in pumping and water use of 20% across the season.

10.4.2.4. Labour and Travel associated with Management

The large distance between Aaron's home and the farm means that we need to consider the trip to the farm in two parts, part A the drive to the farm shed and part B the trip from the farm shed around the farm itself.

Part A involves a return trip including:

2 x 4 km at 50 km/hr (within Home Hill)
2 x 31 km at 95km/hr (within 100km/hr zone)
The result is a return trip of 70 km at 86 km/hr taking 48.8 minutes.

Part B will be considered as 3 km at 15 km/hr taking 12 minutes.

Aaron has estimated that the automation system has saved an average of 3 trips to the farm each week. Aaron still visits the farm for other reasons in addition to these three specific irrigation related trips. Hence Aaron will save 3 part A trips per week.

Under manual operation it is assumed that Aaron will require at least one visit to the field for each irrigation, this differs from the other two growers who would check the progress of the irrigation and visit the field two times. Like for the other farms, each visit to the field will consume 25 minutes of Aaron's time as defined in 10.2.4.2 and a part B trip around the farm.

It was assumed that Aaron saves 3 trips per week to the farm shed of 70km at 86 km/hr. Aaron will save one 3km trip from the farm shed to the fields for each irrigation event. Vehicle costs will be 32c/km as defined in 10.2.4.3. Each visit to the fields will consume 25 minutes of his time as defined in 10.2.4.2 in addition to the travel time.

10.4.2.5. Potential yield gain

The soils at this site are particularly challenging as they possess a low water holding capacity and also suffer from poor infiltration rates. The impact of this limitation was observed by Aaron where a neighbouring drip irrigation field yielded an extra 20 t/ha while at the same time having a higher gross water use. It is reasonable to assume that yield increases will occur with the improved irrigation scheduling possible though automation. A conservative yield increase of 10t/ha will be assumed for the analysis below

Two scenarios will be used for the cost benefit analysis:

- No yield gain
- 10 tonne/ha yield gain which represents a 5% cane yield increase which could be easily achieved if the automation permits better timing of irrigation events.

It was assumed that additional yield would net $30 per tonne after harvesting costs. It was assumed that 80% of the area is harvested each year therefore this yield gain would only occur over 80% of the automated area.

10.4.3. Breakdown of potential benefits for Linton

The assumptions above allow us to predict potential benefits associated with adoption of the automation system. These will be used to generate the scenarios in the following section.

Number of events:

11 blocks x 20 events per year = 220 events per year

Vehicle costs

Part A:	3 trips per week @ 70km	= 10,920 km per year
Part B:	20 events x 1 trips per event @ 3km	= 660 km per year
	Total:	= 11,580 km

Fuel and Maintenance cost @ 32c per km = $3,705.60

Potential labour savings:

220 events x 1 visit @ 25 minutes for each visit = 91.67 hours
91.67 hours @ $30 per hour = $2,750.00

Part A Travel time, 10,920km @ 86km/hr = 126.98 hours
Part B Travel time, 660km @ 15km/hr = 44 hours
Total: = 170.98 hours
170.98 hours @ $30 per hour = $5,129.30

Total Labour saving = $7,879.30

Potential Electricity Tariff saving:

Energy cost under current management on tariff 66 = $15,206.59
Energy cost under current management on tariff 65 = $10,620.91
Energy cost under current management on tariff 62 = $8,719.64
Potential saving moving from tariff 66 to tariff 62 under current management = $6,486.96

Potential power saving:

Assuming that manual control results in an excess pumping of 20%
20% extra power use on tariff 66 = $1,902.22

Potential water saving:

Assuming that manual control results in an excess water use of 20% which can be eliminated with automated control:
Water saving of 97.2 ML @ $0.52 per ML = $50.55

The analysis assumes that the water saved is within the excess usage charge.

Benefit of potential yield increase:

10 t/ha over 80% of 53 ha = 424 tonnes
424 t @ $30/tonne = $12,720

10.4.4. Cost Benefit Results for Current system at Linton site

10.4.4.1. NPV analysis

Six different scenarios were chosen to conduct the cost benefit analysis. The calculations have used a discount rate of 5% per annum and have assumed a 7 year timeframe for NPV and IRR. The scenarios tested are as follows:

1. Complete system with no impact on management or crop yield
2. Complete system with a 20% reduction in water use, no change in crop yield
3. Complete system with a 20% reduction in water use, 10 t/ha yield increase
4. System without base station, no change in water use and a 10 t/ha yield increase
5. System without base station, 20% reduction in water use, 10 t/ha yield increase
6. System without flowmeters and including ½ of base station, no change in water use, 10 t/ha yield increase

Scenarios 4 and 5 are the most representative of the system installed during the project because this farm already had the base station and associated hardware and software installed on a PC in the farm shed.

Scenario 6 represents the situation where the flowmeters are not required or already installed by the scheme and that only ½ of the base station needs to be included which makes sense in this case as this base station controls a similar area of drip irrigation.

Scenario 1 – Complete system with no impact on management

Costs: Complete system including base station & pump controls, and flowmeters
Benefits: Labour, travel time, vehicle costs
Water/Energy: No change
Yield: No change

Capital cost	$68,365.00		NPV (7 year timeframe)	+$31,382
Annual Cost	$150.00		Payback period	4.54 years
Maintenance Cost	$683.65		IRR (7 year timeframe)	+ 16.6 %
Gross Annual Benefit	$18,071.86			
Net Annual Benefit	$17,238.21		Capital cost over 7 years	$9,766

Scenario 2 – Complete system with 20% reduction in water use no yield increase

Costs: Complete system including base station & pump controls, and flowmeters
Benefits: Labour, travel time, vehicle costs
Water/Energy: 20% reduction
Yield: No change

Capital cost	$68,365.00		NPV (7 year timeframe)	+ $42,681
Annual Cost	$150.00		Payback period	4.02 years
Maintenance Cost	$683.65		IRR (7 year timeframe)	+ 20.4 %
Gross Annual Benefit	$20,024.63			
Net Annual Benefit	$19,190.98		Capital cost over 7 years	$9,766

Scenario 3 – Complete system with 20% reduction in water use and 10t/ha yield

Costs: Complete system including base station & pump controls, and flowmeters
Benefits: Labour, travel time, vehicle costs
Water/Energy: 20% reduction
Yield: 10 t/ha increase (on 80% of area)

Capital cost	$68,365.00		NPV (7 year timeframe)	+ $116,284
Annual Cost	$150.00		Payback period	2.33 years
Maintenance Cost	$683.65		IRR (7 year timeframe)	+ 42.8 %
Gross Annual Benefit	$32,744.63			
Net Annual Benefit	$31,910.98		Capital cost over 7 years	$9,766

Scenario 4 – Complete system without base station, including flowmeters, no change in water use and 10t/ha yield increase

Costs: Complete system no base station but including pump controls and flowmeters
Benefits: Labour, travel time, vehicle costs
Water/Energy: No change
Yield: 10 t/ha increase (on 80% of area)

Capital cost	$60,665		NPV (7 year timeframe)	+ $113,130
Annual Cost	$150.00		Payback period	2.19 years
Maintenance Cost	$606.65		IRR (7 year timeframe)	+ 46.0 %
Gross Annual Benefit	$30,791.86			
Net Annual Benefit	$30,035.21		Capital cost over 7 years	$8,666

Scenario 5 – Complete system without base station, including flowmeters, 20% reduction in water use and 10t/ha yield increase

Costs: Complete system no base station but including pump controls and flowmeters
Benefits: Labour, travel time, vehicle costs
Water/Energy: 20% reduction
Yield: 10 t/ha increase (on 80% of area)

Capital cost	$60,665		NPV (7 year timeframe)	+ $124,429
Annual Cost	$150.00		Payback period	2.04 years
Maintenance Cost	$606.65		IRR (7 year timeframe)	+ 49.6 %
Gross Annual Benefit	$32,744.63			
Net Annual Benefit	$31,987.98		Capital cost over 7 years	$8,666

Scenario 6 – Complete system with ½ of base station, no flowmeters, no change in water use and 10 t/ha yield gain

Costs: Complete system: ½ of base station cost, pump controls no flowmeters
Benefits: Labour, travel time, vehicle costs
Water/Energy: No change
Yield: 10 t/ha increase (on 80% of area)

Capital cost	$53,050		NPV (7 year timeframe)	+ $121,186
Annual Cost	$150.00		Payback period	1.89 years
Maintenance Cost	$530.50		IRR (7 year timeframe)	+ 54.0 %
Gross Annual Benefit	$30,791.86			
Net Annual Benefit	$30,111.36		Capital cost over 7 years	$7,579

The net positive value (NPV) in all cases based on the 7 year life of the system in all six scenarios is positive meaning that the estimated benefits are able to recover the initial capital cost.

10.4.5. Benefits Breakdown

The results from scenario 5 will be used to demonstrate the relative contributions to the annual benefits associated with the automation. Figure 10-5 contains a summary of those benefits expressed on a per hectare basis. The gross benefits of automation under this scenario sum to $617.82 per hectare. The capital cost of the system in scenario 5 split over 7 years is $8,666 or $163.52 per hectare.

The consumptive charge of water for this property is very low and therefore the 20% reduction in water use did not have much impact on the results at only 95c per ha. However, the reduced pumping associated with this 20% drop in water use saves $35.89/ha based on tariff 66. This result is scalable, a 10% decrease in water use would have resulted in $17.95/ha saving in electricity use.

The vehicle costs and travel time represent $69.92/ha (11%) and $96.78/ha (16%) of the gross benefits, a total of $166.70 per hectare which is significant because of the distance that Aaron must drive to reach the site. This combined travel cost of $166.70 is, by itself, slightly higher than the capital cost of $163.52 which indicates that travel cost saving alone will justify the system. The vehicle cost is comprised of $65.93/ha of travel to the farm and $3.98/ha travel around the farm itself. This vehicle cost only represents the running costs and would double if the full costs of the vehicle were considered.

In addition to the travel time saving of $96.78/ha there is an additional $51.89/ha associated with the setting up of each irrigation event assuming that Aaron needs to visit the field once per irrigation event. This analysis does not have any allowance for checking the event while underway which would further increase this cost.

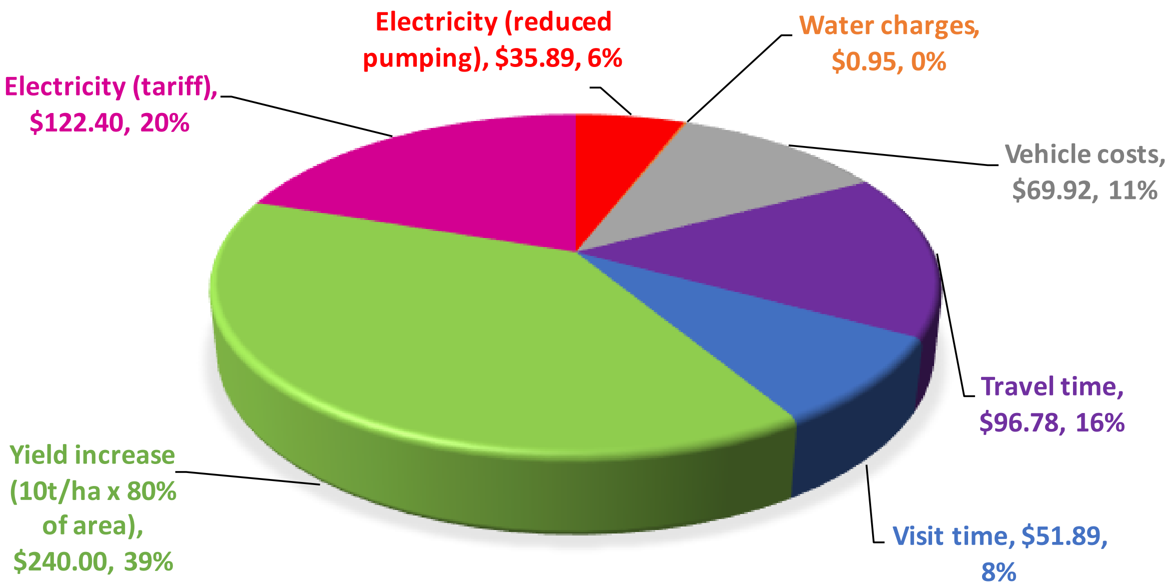


Figure 10-5 – Breakdown of benefits per hectare from Linton site, scenario 5

The total labour savings accrue to $148.67/ha or $7,879.30 for the entire farm. This 263 hours of labour reflects the minimum time that would be required to undertake the tasks. This would likely increase significantly if Aaron sourced external labour.

The saving related to electricity tariffs is worthy of special mention. Under current management based on measured pump run times the saving from simply switching from tariff 66 to 62 results in a $6,487 saving ($122.40 per ha) which is equivalent to 3/4 of the total system cost split over 7 years. This saving is not assumed but is based on the actual observed pumping times during the past financial year.

Finally, the benefits associated with the assumed yield increase of 10 t/ha amount to $12,720 per year ($240/ha) which by itself is higher than the full cost of the system split over 7 years. Like for the other fields, the relative importance of the yield deserves special consideration.

The sensitivity to the yield gain was investigated further, selecting 3 of the scenarios above and varying the yield gain from 0 to 10 t/ha. All other factors were held consistent with the results above including the discount rate of 5%. The three scenarios selected were:

- Scenario 1 – Full system cost, vehicle and labour savings
- Scenario 3 – Full system cost, vehicle, labour and water savings
- Scenario 6 – ½ of the base station and no flowmeters, vehicle, labour and no water saving

Figure 10-6 summarises the findings of this sensitivity analysis in terms of payback period and clearly shows the impact of yield.

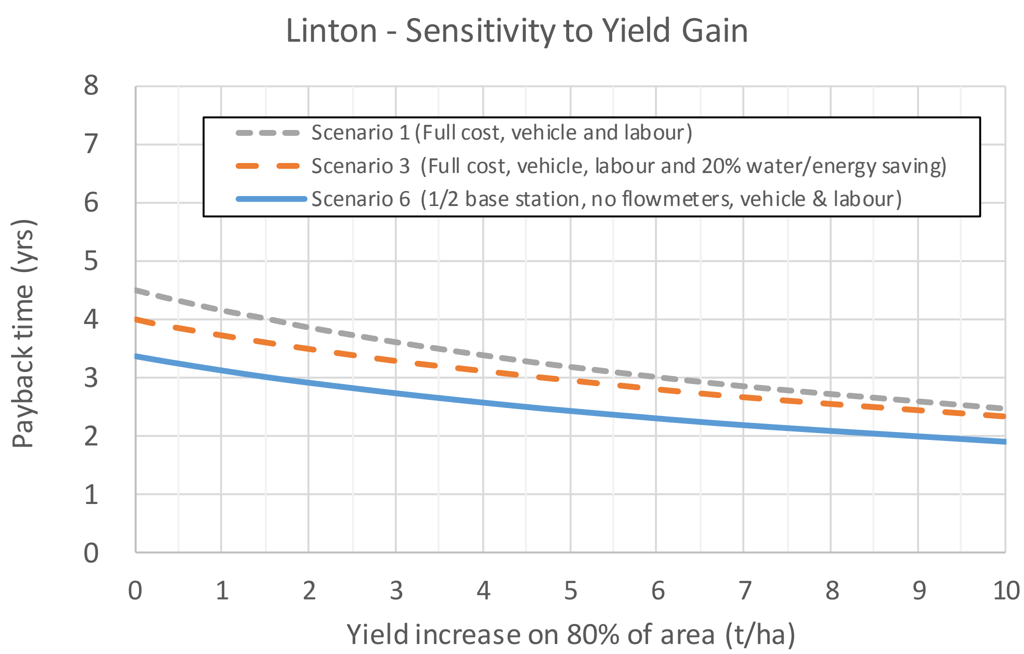


Figure 10-6 – Sensitivity of payback period to yield increase for Jordan site, scenarios 1, 3 & 6

Scenario 1 represents the highest cost case, scenario 3 the highest benefit case and scenario 6 the lowest capital cost case. All three scenarios achieve a payback period better than 5 years with no yield gain. The payback period can be reduced by about 1 year by increasing the yield by 5 t/ha and a further ½ a year by increasing the yield by 10 t/ha.

Unlike the Pozzebon case, acceptable payback times are possible with no change in yield but the Linton site is the site most likely to achieve a yield benefit.

10.5. Jordan Analysis

10.5.1. System Costs

The design for the Jordan site is detailed in 6.5. In this case the automation system is installed over 5 irrigation blocks covering an area of 82 ha as shown in Figure 6-33. The full costings of the automation system at a commercial rate installed at site are given in Table 6-8. A summary of those costs is as follows:

Table 10-6 Summary of costs at Jordan site

	Cost	Per Ha
Base station	$6,900	
Pump site	$800	
Block control	$19,500	
Advance Measurement	$16,500	
Commissioning	$5,000	
Full System	$48,700	$593.90
Full system without base station	$41,800	$509.76
Full system without advance (base station included)	$32,200	$392.68

10.5.2. Jordan Assumptions

10.5.2.1. Pumps and Energy

This field does not have any pumping and therefore there will be no possible energy saving.

10.5.2.2. Water Supply

The sole water source at this site is the SunWater Burdekin Haughton scheme channel which flows along the top end of the field. SunWater charge an allocation fee of $38.41/ML plus a water usage charge which is presently $28.70 per ML. At present Russell does not have any capacity to recycle tail water and so any runoff will be deemed a loss to the system. As explained in section 10.2.3.2 there are three possible scenarios which will lead to a cost saving:

a) Grower is currently within allocation, and is able to reduce water use, saving of $28.70/ML.
b) Grower is within allocation, is able to reduce water use and able to temporarily sell water to other growers, saving of $59.43/ML (made up of usage of $28.70 and selling excess at $30.73)
c) Grower is currently over allocation and is currently buying extra water but can now save water, saving of $67.11/ML

The subsequent analysis will assume that Russell is able to save water and sell the saved water leading to a combined price of $59.43 per ML

10.5.2.3. Irrigation Management

There have been over 100 individual irrigation events at this site since the installation of the furrow irrigation system in April 2016. The analysis here will focus on the 12 months between the 01/07/2016 and 01/07/2017.

- On the plant blocks, there was an average of 24 events during this year period
- On the ratoon blocks, there was an average of 14 events during this year period

It is assumed that in a typical year there will be 1 block of plant and 4 blocks of ratoon and therefore 1 x 24 + 4 x 14 = 80 irrigations per year.

These 80 events, over the 5 blocks, equate to an average 16 events per year per block which is fewer than for the other sites but that is expected because the clay soil at this site should allow use of larger deficits between irrigations.

It is suggested that automation systems allow the grower to start and stop irrigation events at the correct time rather than at a time which is convenient for manual control. It is also suggested that the use of end of row sensors enables the grower to determine when the irrigation has completed without having to visit the field. As discussed above in the case of this field, these sensors were located some distance from the tail drain to give the system sufficient notice to stop the event at the correct time. Russell has in fact taken the automation one step further, setting the irrigation schedule to automatically switch to the next set when water is detected at the selected trigger point.

The cost benefit analysis requires an assumption on the impact of automation on the irrigation schedule. The advance detection sensor is located at the correct place such that the irrigation can be turned off while still ensuring that water will reach the end of the field. This sensor typically detects water 1-2 hours before water reaches the end of the field. This equates to a direct potential saving of 1-2 hours of runtime per irrigation event, even if the grower is on site standing at the end of the field waiting to observe the water flowing out the drills.

Furthermore, it will be assumed that, under manual monitoring and control, on a typical irrigation water would have been discharging from the end of the field for 1 to 2 hours before the grower reaches the site and take the necessary action. The combined potential saving for each event would be approximately 3 hours of inflow time. The inflow rate varies between blocks but averages 129 L/s across the 5 blocks considered. This three hour saving across every event in the season equates to approximately 1.36 ML/ha or just over 10% of the total volume applied.

It was assumed that the automation system saves a potential 3 hours of flow per event at a nominal flowrate of 129 L/s.

10.5.2.4. Labour and Travel associated with Management

For Russell, it will be assumed that there will be 2 visits on average to the field for each irrigation event. Russell Jordan lives relatively close to the site but a return trip to the field including a single circuit around the circumference of the field involves:

- 2 x 1.1 km Russell's driveway at 20 km/hr
- 2 x 5.4 km on gravel roads at 60 km/hr
- 2 x 3.6 km on bitumen road at 90 km/hr
- 1 x 5 km around field at 25 km/hr

The result is a trip of 25.2 km at 44.2 km/hr taking 34.2 minutes. Russell may use a ute, 4-wheeler or tractor but it will be assumed that all travel to the site is done using 4wd utility.

A nominal distance of 25.2 km will be assumed for each trip to the field at a speed of 44.2km/hr, vehicle costs will be 32c/km as defined in 10.2.4.3. Each visit will consume 25 minutes of his time as defined in 10.2.4.2 in addition to the travel time.

10.5.2.5. Potential yield gain

Automation may offer a potential yield gain if it allows the irrigations to better satisfy the crop requirements. A soil water balance completed with IrrigWeb indicates that there are occasions when the current management is not able to adequately replenish the root zone. This means that there should be a potential to increase production if the irrigation management is optimised. The small amount of data available does not allow quantification of the potential yield benefit so a small increase of 5t/ha has been assumed for this analysis.

Two scenarios will be used for the cost benefit analysis:

- No yield gain
- 5 tonne/ha yield gain which represents a 2-3% cane yield increase which could be easily achieved if the automation permits better timing of irrigation events.

10.5.3. Breakdown of potential benefits for Jordan

The assumptions above allow us to predict potential benefits associated with adoption of the automation system. These will be used to generate the scenarios in the following section.

Number of events:

5 blocks x 16 events per year = 80 events per year

Vehicle costs

80 events x 2 trips per event @ 25.2km = 4,032 km per year

Fuel and Maintenance cost @ 32c per km = $1,290.24

Potential labour savings:

80 events x 2 visits @ 25 minutes for each visit = 66.7 hours

66.7 hours @ $30 per hour = $2,000.00

Travel time, 4,032km @ 44.2km/hr = 91.2 hours

91.2 hours @ $30 per hour = $2,736.65

Total Labour saving = $4,736.65

Potential power saving:

NIL

Potential water saving:

Assuming 3 hour reduction in irrigation duration per event:

80 events @ 3 hours @ 129 L/s = 111.5 ML

Usage Charge:

111.5 ML @ $28.70/ML = $3,198.79

If saving is traded at 80% of market price

111.5 ML @ $30.76/ML = $2,568.61 (plus $3,198.79 from usage)

If saving means that water does not need to be purchased (this is not used in the scenarios)

111.5 ML @ $38.41/ML = $3,853.03 (plus $3,198.79 from usage)

Benefit of potential yield increase:

5 t/ha over 80% of 82 ha = 328 tonnes

328 t @ $30/tonne = $9,840

10.5.4. Cost Benefit Results for Current system at Jordan site

10.5.4.1. NPV analysis

Six different scenarios were chosen to conduct the cost benefit analysis. The calculations have used a discount rate of 5% per annum and have assumed a 7 year timeframe for NPV and IRR. The scenarios tested are as follows:

1. Complete system with no change to management or crop yield
2. Complete system with a 3 hour reduction in water use, no change in crop yield
3. Complete system with both a 3 hour reduction in water use and 5 t/ha yield increase
4. System without base station, no change in water use and a 5 t/ha yield increase
5. System without base station, 3 hour reduction in water use and a 5 t/ha yield increase

Scenarios 4 and 5 are the most representative of the system installed during the project because this farm already had the base station and associated hardware and software installed on a PC in the home office.

Scenario 1 – Complete system with no change to management

Costs: Complete system including base station
Benefits: Labour, travel time, vehicle costs
Water/Energy: No change
Yield: No change

Capital cost	$48,700		NPV (7 year timeframe)	- $16,644
Annual Cost	$0.00		Payback period	11.86 years
Maintenance Cost	$487.00		IRR (7 year timeframe)	- 11.9 %
Gross Annual Benefit	$6,026.89			
Net Annual Benefit	$5,539.89		Capital cost over 7 years	$6,957

Scenario 2 – Complete system with 3 hour reduction in water use

Costs: Complete system including base station
Benefits: Labour, travel time, vehicle costs
Water/Energy: Reduction of 3 hours per irrigation
Yield: No change

Capital cost	$48,700		NPV (7 year timeframe)	+ $16,728
Annual Cost	$0.00		Payback period	4.99 years
Maintenance Cost	$487.00		IRR (7 year timeframe)	+ 13.9 %
Gross Annual Benefit	$11,794.29			
Net Annual Benefit	$11,307.29		Capital cost over 7 years	$6,957

Scenario 3 – Complete system with 3 hour reduction in water use and 5t/ha yield increase

Costs: Complete system including base station
Benefits: Labour, travel time, vehicle costs
Water/Energy: Reduction of 3 hours per irrigation
Yield: 5 t/ha increase (on 80% of area)

Capital cost	$48,700		NPV (7 year timeframe)	+ $73,666
Annual Cost	$0.00		Payback period	2.51 years
Maintenance Cost	$487.00		IRR (7 year timeframe)	+ 39.12 %
Gross Annual Benefit	$21,634.29			
Net Annual Benefit	$21,147.29		Capital cost over 7 years	$6,957

Scenario 4 – Actual case, complete system but no base station, 3 hour water saving

Costs: Complete system without base station
Benefits: Labour, travel time, vehicle costs
Water/Energy: Reduction of 3 hours per irrigation
Yield: no change

Capital cost	$41,800		NPV (7 year timeframe)	+ $14,027
Annual Cost	$0.00		Payback period	4.16 years
Maintenance Cost	$481.00		IRR (7 year timeframe)	+ 19.31 %
Gross Annual Benefit	$11,794.29			
Net Annual Benefit	$11,376.29		Capital cost over 7 years	$5,971

Scenario 5 – Actual case, complete system but no base station, 3 hour water saving and 5 tonne yield increase

Costs: Complete system without base station
Benefits: Labour, travel time, vehicle costs
Water/Energy: Reduction of 3 hours per irrigation
Yield: 5 t/ha increase (on 80% of area)

Capital cost	$41,800		NPV (7 year timeframe)	+ $80,965
Annual Cost	$0.00		Payback period	2.13 years
Maintenance Cost	$481.00		IRR (7 year timeframe)	+ 11.8 %
Gross Annual Benefit	$21,634.29			
Net Annual Benefit	$21,216.29		Capital cost over 7 years	$5,971

The net positive value (NPV) is negative in scenario 1 but positive for all other scenarios. Scenario 1 is the one with no change in management and no yield increase which indicates that the system costs will only be justified if there is either a water saving or yield increase. Scenario 2, with a 3 hour decrease in water use per irrigation reduces the payback period to 4.99 years and internal rate of return of 13.9%. Scenario 3 by adding a 5t/ha yield gain halves this payback period to 2.51 years.

The payback periods for this site are much faster than the other sites due to the lower capital costs per unit area, which are less than half of that of the other two sites.

10.5.4.2. Benefits Breakdown

Scenario 5 is chosen to illustrate the potential benefits of automation at this site. The results from this scenario will be used to demonstrate the relative contributions to the annual benefits associated with the automation. Figure 10-7 contains a summary of those benefits expressed in terms of dollars per hectare.

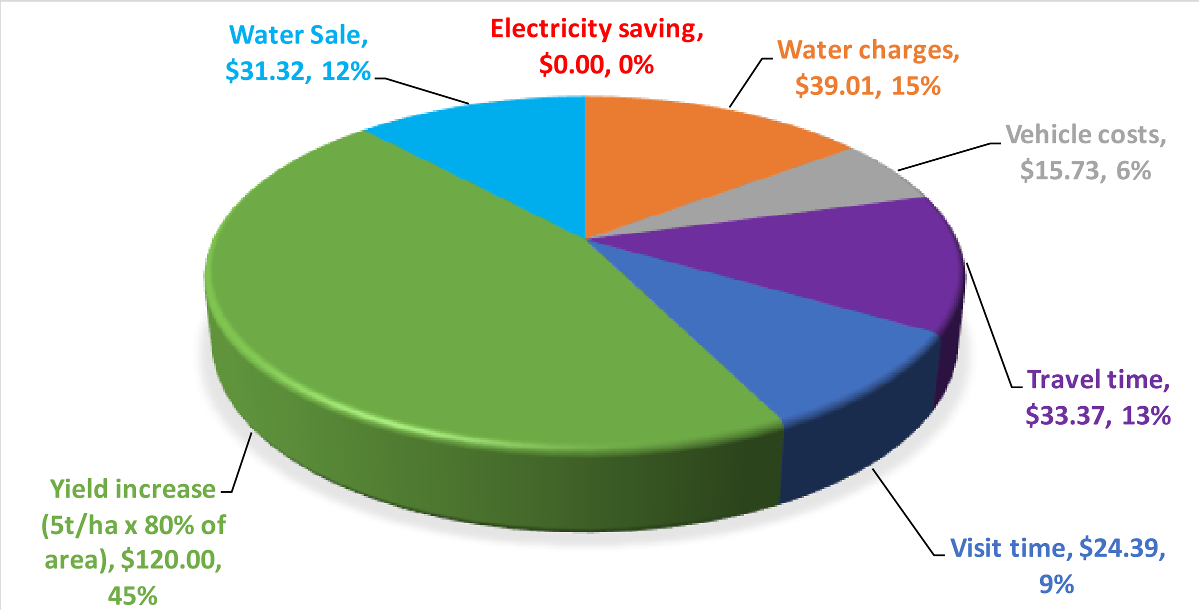


Figure 10-7 – Breakdown of benefits from Jordan site (current) per hectare for scenario 5.

The single largest benefit, and the most difficult to accurately predict, is the potential yield increase. A 5t/ha increase corresponds to $120 per ha or 45% of the potential benefit.

The labour savings at the Jordan site are far smaller per hectare than compared to the other two sites which is a result of the larger irrigation set sizes and to a lesser extent the fewer number of irrigations per season. The combined labour savings equate to $57.76 per ha which is comprised of the visit travel time ($33.37/ha) and the visit time ($24.39/ha). These costs seem low on a per hectare basis but total to $4,736.65 across the farm area. The labour saving for these 5 blocks alone equates to approximately 4 weeks of full time employment per season at 40 hours per week. In a similar manner, the vehicle costs are also quite low on per ha basis at $15.73/ha.

The remaining two components, the water use charges and the potential water sale revenue sum to $70.33/ha which is larger than the predicted labour saving. This benefit would increase slightly if Russell was previously purchasing water on top of his allocation.

10.5.4.3. Sensitivity to Yield

Out of all benefits, the yield increase is the most difficult to estimate reliably as it is influenced by many factors independent of the automation system. The sensitivity of the benefits to this assumed yield benefit was analysed by selecting three of the above scenarios and varying the yield gain from 0 to 10 t/ha. All other factors were held consistent with the results above including the discount rate of 5%. The three scenarios selected were:

- Scenario 1 – Full system cost, vehicle and labour savings
- Scenario 3 – Full system cost, vehicle, labour and water savings
- Scenario 5 – System cost without base station, vehicle, labour and water savings

Figure 10-8 summarises the findings of this sensitivity analysis in terms of payback period and clearly shows the impact of yield.

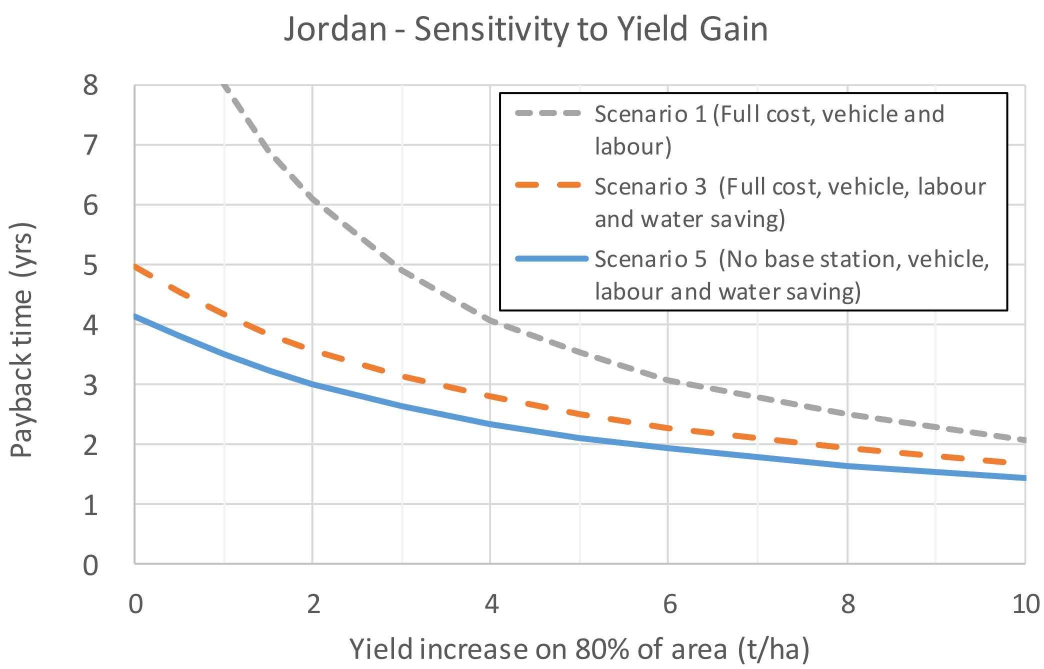


Figure 10-8 – Sensitivity of payback period to yield increase for Jordan site

Figure 10-8 shows that it is relatively easy to meet the 7 year payback timeframe across the three scenarios considered. Scenarios 3 and 5 have 5 and 4 year paybacks respectively with no yield increase and these payback times can be halved through a 5 t/ha yield increase. For Scenario 1 with no water saving it would take a yield increase of only 1.5 t/ha to payback the capital within the 7 year timeframe. The results here add more evidence to the earlier statement that the system is cost effective with either a yield increase or water saving and if both occur the payback period will be quite fast.

10.6. Conclusions

10.6.1. Summary of Results

This chapter has outlined the costs and potential financial benefits of adopting automation of furrow irrigation across three farms of varying size and water source. Table 10-7 summarises this data across the three sites including the hypothetical Pozzebon entire farm scenario. The costs per unit area range from the Jordan site at $594/ha to the Linton site at double the cost at $1,290/ha to the Pozzebon site at almost 4 times that of the Jordan site at $2,211/ha. One might expect that the cost benefit would be inversely related to this price and that the lower cost would have the greatest net benefit but the truth is more complex. The labour saving per unit area is proportional to the size of the blocks, therefore the Jordan site has a labour saving much lower than that of the other three sites.

Table 10-7 Summary of cost benefit analysis

		Pozzebon	Pozzebon Entire F.	Linton	Jordan
	Area (ha)	27	87	53	82
	Number of blocks	8	24	11	5
	Cost for full system ($)	$59,700	$120,300	$68,365	$48,700
$/ha	Cost for full system	$2,211	$1,383	$1,290	$594
$/ha	Cost per year over 7 years	$316	$198	$184	$85
$/ha	Labour Saving	$197	$184	$149	$58
$/ha	Vehicle cost saving	$10	$10	$70	$16
$/ha	Water Saving	$86	$80	$1	$70
$/ha	Energy saving	$25	$23	$36	--
$/ha	Electricity tariff saving	$0	$0	$122	--
$/ha	**Sum of benefits**	**$318**	**$296**	**$378**	**$144**
$/ha	Yield Increase	$120	$120	$240	$120
$/ha	**Sum benefits + Yield**	**$438**	**$416**	**$618**	**$264**
Payback (yrs)	**Scenario 1** (no water saving and no yield increase)	18.5	9.99	4.54	11.9
Payback (yrs)	**Scenario 2** (water saving but no yield increase)	9.59	5.77	4.02	4.99
Payback (yrs)	**Scenario 3** (water saving + yield increase)	6.34	3.88	2.33	2.51

The Linton site is the only one which makes economic sense with or without any change to management or yield increase (Scenario 1). The other sites will only be cost effective if the farmer achieves either a yield increase or a water saving.

Based on the three sites, growers will see an economic benefit associated with automation if they are able to achieve either a water saving or a yield increase through adoption of the technology. Both of these aspects require some form of change to the irrigation management to better tailor the irrigation schedule and applied volumes to the crop. While these benefits are theoretically possible without automation, it is the automation which makes these practically achievable

10.6.2. Potential for Reduced Costs

The project team instrumented each field with a complete set of equipment which was low cost but was also robust enough to sustain the assumed 7-year life of the system. It is true that the cost of certain components could be reduced, e.g. selecting lower grade linear actuators or less expensive water advance detectors but it is likely that this would reduce the expected life of the system. The same applies to the WiSA system itself, which is designed to be robust and withstand farm conditions while being capable of connecting to a wider range of sensors and devices than this project had the opportunity to test.

One major advantage of WiSA over alternative systems is the ability to connect two linear actuators to a single node, which is not important for the border check irrigation systems for which these systems were developed as control gates are usually spaced >50m apart. In the sugar industry, each riser will contain two valves so the ability to control two actuators directly from the one valve is very useful.

The WiSA hybrid board (which represents all control and advance nodes in this project) is actually capable of controlling 4 actuators, however, in most furrow irrigation situations, at most only 2 valves are ever in close proximity to connect directly to the hybrid board. The high power draw of the linear actuators means that the wiring from the node to the actuator must be less than 15 m long. AgriTech Solutions has worked with WiSA to develop a solution to connect remote actuators to a hybrid board where a remote actuator is more than 15 m from a hybrid board. The hybrid board will monitor and control the remote unit through cables that will be trenched and buried at a safe depth. The remote unit situated at the valve will contain a 12 V battery, solar panel and relays that will open and shut the actuator(s). The cost of this remote unit will be much lower than the $3,000 cost for the fully installed WiSA Hybrid Board

The pump controller also has unutilised capacity, and can be used to control and monitor multiple actuators with a similar setup, as described above.

While it is anticipated that the number of hybrid boards will be reduced, other costs including trenching, electrical conduit, and cable from the WiSA board to the remote units, must be considered. The distance of the remote units from either the hybrid board, or the pump controller, will determine the final savings. It is anticipated that the savings will be around 10 – 30% from the original designs. Clearly, the savings will be on a case-by-case situation. AgriTech solutions is currently looking to trial this approach to identify the practical aspects and final cost of this alternative design.

10.6.3. Conclusion

The cost benefit analysis has shown that the capital costs associated with the conversion of traditional furrow irrigation to automated furrow irrigation can be recovered through a range of financial benefits. The cost for the full system including the base station ranged between $594 and $2,211 per hectare which was mostly a factor of the irrigation set size, with the lower costs being for those farms with larger sets. When spread over the expected 7-year life of the system these costs equate to a range between $85 and $316 per hectare per season.

The largest single benefit is the monetary value of the labour saving, ranging between $58 to $197 per hectare, which is achieved by the fact that the grower does not need to visit the field to attend to every remedial irrigation management activity. The cost savings associated with vehicle travel were up to $70 per hectare depending on the distance travelled to reach the site.

The capital costs on one of the three farms could be recovered in 5 years without any yield gain or change in water or energy use but in the other cases a favourable economic outcome was dependent on the grower achieving either a small yield benefit or increase in water use efficiency.

The three farms in this project have provided a good range of costs and financial benefits and have highlighted the fact that a favourable cost benefit scenario is reliant on the characteristics of the farm design, water sources and current management. Some growers may see no net financial benefit, some may see extensive benefits while others may only realise the benefits when the system allows them to improve their irrigation scheduling and management. Growers should be encouraged to consider how automation might fit with their own farming enterprise and will need assistance in developing their own cost benefit analysis to inform their decision on whether to invest in these systems.

This cost benefit analysis has attempted to account for the impact of reducing irrigation labour requirements from a purely financial perspective but this grossly underestimates the actual benefits to the grower's quality of life and improved sleeping habits. The social benefits will also extend to the grower's family as they now will be able to better prioritise family commitments.

The cost benefit analysis also does not consider the potential for better managing irrigation induced runoff and/or deep drainage and the dissolved agri-chemicals which it may contain.

11. PUBLICATIONS

11.1. SRA Handouts and project publications:

Handouts associated with Smarter Irrigation:

Smarter Irrigation for Profit project Overview - http://www.cottoninfo.com.au/publications/water-smarter-irrigation-profit-projects

SRA Handouts:

Automation of furrow irrigation Overview
https://sugarresearch.com.au/wp-content/uploads/2017/02/Automation-of-furrow-irrigation.pdf

Automation of furrow irrigation – Fact Sheet 1 - Russell Jordan
https://sugarresearch.com.au/wp-content/uploads/2017/02/Automation-of-furrow-irrigation-IS-1.pdf

Automation of furrow irrigation – Fact Sheet 2 - Aaron Linton
https://sugarresearch.com.au/wp-content/uploads/2017/02/Automation-of-furrow-irrigation-IS-2.pdf

Automation of furrow irrigation – Fact Sheet 3 - Denis Pozzebon
https://sugarresearch.com.au/wp-content/uploads/2017/02/Automation-of-furrow-irrigation-IS-3.pdf

11.2. Posters and Conference Papers

Gillies, M., Attard, S. Foley, J. Uddin, J (2015) Automatic Furrow Irrigation System for Sugar Cane, International Society of Sugar Cane Technologists - Agricultural Engineering, Agronomy and Extension Workshop, Salt Rock, South Africa, 24th – 28th August. [POSTER]

Gillies, M., Attard, S., Jaramillo, A., Davis, M., Foley, J. 2017. Smart Automation of Furrow Irrigation in the Sugar Industry, Proceedings of the 39th Conference of the Australian Society of Sugar Cane Technologists held at Cairns, Queensland, Australia, 2 - 5 May 2017. [PAPER]

11.3. Industry Publications and Magazine Articles

BPS (2017) March 2017 Grower Update – Automation of Furrow Irrigation, P4

SRA (2017), Cane Connection Spring 2017 – Automation:1 110 fewer hours per year sitting in the ute, pp 14-15. https://sugarresearch.com.au/wp-content/uploads/2017/09/CaneConnection-Spring-17-F-LowRes.pdf

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GVIA (2017) – 2017 Grower-led Irrigation Research Field Day – Lessons Learnt from Modernisation of Furrow Irrigation in the Sugar Industry, p15, http://irec.org.au/wp-content/uploads/GVIA-2017-FD-Booklet-LOW-RES.pdf

BPS (2016) June 2016 Grower Update – Automation of Furrow Irrigation Field Walk, P8, http://bps.net.au/cms/wp-content/uploads/2013/09/Ed-22-June-2016-BPS-Grower-Update.pdf

11.4. International Journal Articles

Gillies. M. Attard, S. Foley. J. (2018) *Modernised Furrow Irrigation System for Sugar Cane*, paper under preparation which will be submitted to Irrigation Science.

11.5. Book Chapters

Gillies, M. Foley, J, McCarthy, A. (2017) Chapter 10 - Improving Surface Irrigation. In: *Advances in Agricultural Machinery and Technology*. CRC Press, Taylor and Francis Books.

11.6. Other Articles

ABC (2017) ABC News - Financial and social benefits flow for farmers trialling automated irrigation

http://www.abc.net.au/news/rural/2017-08-15/automated-irrigation-trials-underway-on-sugar-cane-farms-qld/8808972

11.7. Internal Reports

Gillies, M. Foley, J, Attard, S (2017) Smart irrigation for Profit Milestone Report April 2016: *Russell Jordan Site 2016-2017 season*. Internal report for Rural R&D for Profit.

Gillies, M. Foley, J, Attard, S (2016) Smart irrigation for Profit Milestone Report April 2016: *Russell Jordan Site 2015-2016 season*. Internal report for Rural R&D for Profit.

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Gillies, M. Foley, J, Uddin, S, McCarthy, A (2016) Smart irrigation for Profit Milestone Report April 2016: *Review of Commercially Available Automation Equipment for Surface Irrigation Automation*. Internal report for Rural R&D for Profit.

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