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Final Report

Improving water quality for the Great Barrier Reef and wetlands by better managing irrigation in the sugarcane farming system

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JAMES COOK UNIVERSITY AUSTRALIA

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This report is available for download from the NESP Tropical Water Quality Hub website:
http://www.nesptropical.edu.au

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ACRONYMS

BPS............... Burdeking Productivity Services
CWU.............. Crop water use
DAWE .... Department of Agriculture, Water and the Environment
DIN .... Ddissolved inorganic nitrogen
GBR .... Great Barrier Reef
IoT................. Internet of Things
JCU .... James Cook University
NESP .... National Environmental Science Program
OGBR .... Office of the Great Barrier Reef
P2R .... Paddock to Reef
RO................. Runoff
RRRC............ Reef and Rainforest Research Centre Limited
SILO.............. Scientific Information for Land Owners
SRA............... Sugar Research Australia
SWD.............. Soil water deficit
TWQ.............. Tropical Water Quality
USQ .... University of Southern Queensland
WA .... Water applied
WQ .... Water Quality
WQIP............. Water Quality Improvement Plan

ABBREVIATIONS

CANEGRO.... a sugarcane crop model
IrrigWeb........ an irrigation decision support tool
N.................... Nitrogen
N/ha/year ...... Nitrogen per hectare per year
t/year............. Tonnes per year
WiSA............. an irrigation automation system

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EXECUTIVE SUMMARY

The Great Barrier Reef (GBR) is an iconic asset that is pivotal to the social and economic well-being of all Australians. In recent years concern has intensified that human-induced pollutants are leaving farming systems and negatively impacting the GBR ecosystem and associated wetlands. Fertilisers in particular are believed to be linked to losses of dissolved inorganic nitrogen which are a major contributor of crown-of-thorns starfish outbreaks. In line with the 2050 water quality improvement plan (State of Queensland, 2018), the revised Burdekin water quality improvement plan (Waterhouse, Attard, Rickert, Buono, & Hunt, 2018) has aspirations to achieve a 60% reduction in dissolved inorganic nitrogen (DIN) by 2025. Because of the strong linkage between irrigation management and DIN losses, managing DIN must involve improved irrigation management and scheduling. The challenge is how to do this in a way that remains both practical and profitable for farmers and, accrues environmental benefits.

Many people propose that smart technologies like automated irrigation systems offer a solution to this problem. Automated irrigation systems like WiSA, can save farmers a significant amount of time by remotely turning on and off pumps and valves. Unfortunately, automatic irrigation systems on their own do not provide (i) any insight on the amount and timing of irrigation required by the crop and (ii) how irrigation schedules should change with soil type, farm management and climate.

To unravel these complex interactions, another smart tool is needed. This tool is in the shape of an irrigation decision support tool like IrrigWeb. Unfortunately due to the high frequency of irrigations across dozens of paddocks, and the need to irrigate almost all year round, day-to-day use of IrrigWeb is not a feasible solution for many farmers. We argue these two SMART technologies are SMARTER when they are 'one'.

The NESP TWQ Hub Project 3.1.2 team, in close partnership with its industry stakeholders, and its industry partners, investigated if the Internet of Things (IoT) could make the two technologies of WiSA and IrrigWeb share data and work together seamlessly as 'one' SMARTER technology. To achieve this, a two-way communication channel was generated between the WiSA and IrrigWeb platforms.

In the first stage, an Uplink program (WiSA to IrrigWeb) was developed and implemented on several sugarcane farms in the Burdekin region. It connects the farmer's WiSA to IrrigWeb by uploading irrigation data automatically. The farmer's irrigation events recorded by WiSA are automatically uploaded into IrrigWeb. This saves farmers time and makes irrigation scheduling much more efficient. Another benefit is that the farmer can co-learn from the decision support tool by observing the exact amount of water applied to each paddock, while comparing to the expected crop water use. The system also allows the farmer to make modifications to the irrigation management if required. Moreover, automating the data transfer from WiSA to IrrigWeb makes it easier for farmers, and thus, can motivate more farmers to adopt these types of technologies and accrue water quality benefits.

In the second stage, a Downlink program (IrrigWeb to WiSA) was developed to download, calculate and apply irrigation schedules. Here, irrigation schedules are dependant on a number of factors which include but are not limited to soil type, farm management, and climate. In this process, sugarcane irrigators will spend less time manually setting up irrigation schedules as it will happen automatically. The simulation results demonstrated the Downlink program improved the scheduling by incorporating practical limitations, such as energy and irrigation system constraints, irrigation priorities at a different time of the year and farmer irrigation preference.

In the third stage, an IoT-based irrigation monitoring system is designed to monitor the implementation of the *smarter* irrigation system. In this stage, detailed information about the recorded irrigation event and rainfall data are collected. Moisture probe values and flow rate data are also collected as a quality control procedure to ensure the irrigation water applied by WiSA, matches the irrigation schedule suggested by IrrigWeb together with the adjustments which allow for practical on-farm constraints. A real-farm trial has been carried out with a duration more than a year on the drip blocks. The trial demonstrated this *smarter* irrigation management system could reliably manage irrigation scheduling on a real farm. To the best of our knowledge, this is the first time an experiment of this type has been performed for any sugarcane system, anywhere in the world.

The combination of Uplink and Downlink embedded in our *smarter* irrigation system offers a cybernetic revolutionary solution that can transform sugarcane irrigation management in the Burdekin catchment that is practical, profitable and environmentally friendly. Specifically, this *smarter* irrigation management system can increase growers' profit margins by increasing production, with less water, and less electricity in practical and efficient ways. It will also deliver environmental benefits, by reducing off-farm losses of agricultutal chemicals, such as nutrients (particularly nitrogen, N) and pesticides contained in irrigation water that leaves the farm via runoff or deep drainage, making an important contribution to achieving the Reef 2050 Water Quality Improvement Plan (WQIP) targets.

1.0 INTRODUCTION

1.1 Background

Together, the Reef 2050 Water Quality Improvement Plan (State of Queensland, 2018) and the revised Burdekin Water Quality Improvement Plan (Waterhouse, Attard, Rickert, Buono, & Hunt, 2018) have aspirations to achieve a significant reduction in dissolved inorganic nitrogen (DIN) in the near future. Reduction in DIN cannot occur by adjusting the nitrogen (N) rate only. Because of the strong linkage between irrigation management and DIN losses, managing DIN must involve both managing the N rate that is applied, and irrigation after that. This project focuses on the latter. To achieve this goal, there will need to be widespread adoption of practices and technologies that deliver high irrigation use efficiency in the Burdekin by 2025. This is easier said than done. Barriers that frequently impede the adoption of new practices and technologies include but are not limited to:

(i) lack of trust;
(ii) fear of disruption;
(iii) limited time to change practice and interact with technologies;
(iv) proof of value;
(v) reliability; and
(vi) a mismatch between what the technology actually delivers and what it should deliver.

If the Burdekin is to achieve a reduction in DIN through improved irrigation practices, then we need a solution to overcome these barriers. Typically, decision support tools such as APSIM (Keating, et al., 2003), CANEGRO (Singels & Bezuidenhout, 2002), WATERSENSE (Inman-Bamber, Attard, Verrall, Webb, & Baillie, 2007), and in the case of the Burdekin, IrrigWeb (www.irrigweb.com) are turned to as a solution to this problem. However, adoption theories tell us that unless the outputs from a decision support tool are reduced to a rule of thumb, they are rarely adopted and applied in practice (Thorburn, Jakku, Webster, & Everingham, 2011). Rarely, is it possible to generate rules of thumb for irrigation management from decision support tools, because the cropping irrigation system is dynamic. This means that IrrigWeb requires frequent updating to obtain precise irrigation scheduling. Farmers typically have more than 20 irrigation management units or fields. Each field usually requires multiple irrigations; between 10 and 20 in the Burdekin region, for most surface irrigated fields, to more than 100 irrigations for subsurface drip irrigation each year. As such, the time commitment to continuously update the information is a significant hurdle to ongoing use and ultimately leads to failed adoption practices because farmers do not have the time to do this.

The Internet of Things (IoT) is the inter-networking of physical devices, vehicles or other items, embedded with electronics, software, sensors, actuators, and communication that enable these objects to “talk” and exchange data – or simply put, making normal things smarter by connecting them (Atzori, Iera, & Morabito, 2010). Smarter devices or “Connected devices”, are designed in such a way that they capture and utilise every bit of data which you share or use in everyday life. These devices will use these data to interact with you daily and complete tasks (Bertino, Choo, Georgakopolous, & Nepal, 2016). This new wave of connectivity is going beyond laptops and smartphones, it is going towards connected cars, smart homes, connected wearables, smart cities and connected healthcare — basically, a connected life.

The IoT technology is also driving the concept of "smart farming", and can transform the industry, enabling farmers to contend with the enormous challenges they face (Ryu, et al., 2015) (Koch, 2017).

1.2 Motivation

Combining the technologies of radio telemetry, solar power and personal computers, the IoT-based automated irrigation system can reduce water use and labour while improving crop quality and quantity (Vellidis, et al., 2016). Gradually, more sugarcane growers in the Burdekin region are transitioning to this solution. The automated irrigation system allows farmers to remotely turn on and off pumps and valves, which can save them a substantial amount of time, water and energy. However, farmers still have to spend a significant amount of time in setting up irrigation schedules, since the automated irrigation system is not able to automatically determine the correct amount of water to apply, which is also one of the most tedious, time-consuming and stressful parts in irrigation management (Connellan, 2002). Moreover, without the consideration of field characteristics, crop class, crop start dates, soil characteristics and weather information, the system cannot provide the optimised irrigation schedule, which could raise the chance of maximising crop yield. A tool is needed to enhance irrigation use efficiency in a way that is convenient for the farmer. The IoT technology can do this by integrating WiSA, the current existing auto-irrigation system, and IrrigWeb.

1.3 Objectives

a. Build on both the confidence and investment that Burdekin Productivity Services (BPS) Ltd have made in IrrigWeb by extending the capacity of local extension staff and farmers to engage with IrrigWeb via on-going training and mentoring.
b. Develop an automated smart IoT precision irrigation system that seamlessly integrates with IrrigWeb to create efficiencies in irrigation practices and increases industry competitiveness.
c. Work in partnership with farmers, extension officers, commercial providers (WiSA, IrrigWeb), research groups (Sugar Research Australia (SRA), NQ Dry Tropics, James Cook University (JCU)) and government agencies (Department of Agriculture, Water and the Environment (DAWE)) as part of an action learning environment, to:
   - Simultaneously harness the ideas, needs and wants of stakeholder groups
   - Identify the perceived or real barriers to the adoption of the precision irrigation system
   - Explore ways to overcome these barriers.
d. Identify pathways that will increase the number of farmers who meet or exceed industry best management practices in relation to irrigation management through the use of the smart IoT precision irrigation system.

2.0 METHODOLOGY

To enhance irrigation use efficiency, in a way that is convenient to the farmer, required developing a *smarter* irrigation system by combining the automated irrigation systems with the irrigation decision support tool. The design and development of this system were underpinned by an agile systems approach which was complemented with broader communication and engagement activities.

2.1 Agile Systems Approach

An agile approach grounded on participatory action learning methods was used in this project to achieve a common level of understanding and progression of activities in a dynamic and exploratory way. Here, the project team worked closely with its consultative group (Figure 1) for honest feedback, inspiration and ideas on how the project team could maximise the project outcomes. The project team would take on-board this constructive advice, go back to the 'office' to figure solutions that they hoped would meet the satisfaction of the industry group. The cycle repeated several times, and as such, the legacy of the project is something useful and practical for industry.

Figure 1: As part of the Agile working methodology, the project team was guided by the consultative group to maximise the project outcomes.

2.1.1 Simulations performed on the JCU Community garden test farm

In order to test the system prior to the implementation on a commercial farm. The project team built a demonstration farm at the Cairns JCU community garden using the auto-irrigation system (WiSA), as shown in Figure 2 and Figure 3.

The simulation is set up to simulate a variety of irrigation system and irrigation management scenarios that could exist in commercial farms:

1) One pump supplying waters for multiple paddocks in one hydraulic group;
2) Two pumps supplying waters for a single paddock in one hydraulic group;
3) Two pumps supplying waters for multiple paddocks in one hydraulic group;
4) Multiple pumps supplying waters for multiple paddocks in one hydraulic group;
5) Farms with/without flow meters;
6) Farms with isolation valves that divide one hydraulic group into two.

This simulation identified and resolved bugs in the system and made a smoother transition to real cane farms. It has also raised public awareness about this project through visits from students, the media and other interested parties. The demonstration garden also serves as a vehicle to raise awareness about the project and has been featured at the JCU website (https://www.jcu.edu.au/brighter/articles/how-the-internet-of-things-can-help-save-the-great-barrier-reef).

Figure 2: JCU Community garden test site

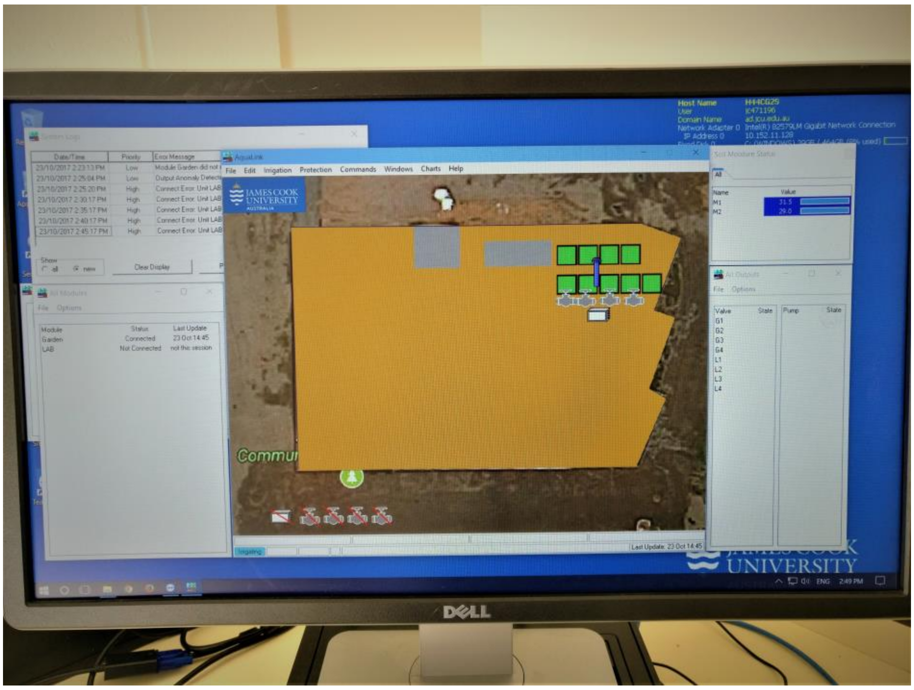

Figure 3: Aqualink software for the JCU Community garden test site

2.2 Broader Communication

A wide range of communication and engagement activities were conducted to inform a wide range of audiences about the project.

2.2.1 Engagement and Awareness Raising

Engagement and awareness raising activities comprised of numerous one-on-one discussions along with small group discussions to develop a common understanding of the goals and constraints of the project.

The project team utilized the existing networks of BPS, SRA and other extension providers via direct discussion with, and between, individual farmers. The project has also communicated project activities to other key organisations, such as NQ Dry Tropics, and University of Southern Queensland (USQ), to mitigate duplication of efforts and explore opportunities for transferability and future collaboration.

2.2.2 Newsletters

The project team submitted a number of newsletters to government departments and local stakeholders and Indigenous groups to inform them of the project objectives and exciting achievements as they occurred throughout the project.

2.2.3 Cairns visit

The project team organised a one-day visit for a group of 14, including Burdekin sugarcane farmers, people from SRA, BPS, AgriTech Solutions and MSF Sugar (https://nesptropical.edu.au/index.php/2018/03/14/nesp-twq-project-3-1-2-james-cook-university-grower-tour/). The group visited various research and teaching facilities at JCU and gained an informed perspective of other research undertaken by the project team using the latest IoT technologies that can be adapted to improve irrigation and agriculture management practices. Moreover, many seminars were held to enhance the project's outcomes and deliverables and to discuss other smart technologies that can benefit agro-environmental systems. Through this visit, farmer and industry participants acknowledged the success of the project to date and endorsed the strategies for the next stages.

2.2.4 Indigenous Consultation and Engagement

The outcomes from this project have a positive impact of water quality going into freshwater ecosystems, including the RAMSAR wetlands and will deliver benefits to the environments utilised in a traditional way. The project team has communicated research outputs and outcomes to relevant Indigenous groups. Specifically, the project team has:

(i) Engaged with many stakeholder groups such as cane farmers and extension staff in the Burdekin cane growing region as well as Indigenous and non-Indigenous school children.

(ii) Continued to engage with the Indigenous community by ensuring that an Indigenous community member receives the project newsletter.

(iii) Presented an overview of the precision irrigation system at a local Burdekin school, to Indigenous and non-Indigenous students.

(iv) Hosted a visit of more 90 high school students who form part of the 'Indigenous Leaders of Tomorrow' group. These students visited JCU to learn about the Internet of Things (IoT) and how the IoT can deliver benefits to wetlands and the Great Barrier Reef by improved irrigation strategies.

2.2.5 Conference presentations and publications

The project team has been actively exploring scientific merits in the project, summarising findings and presenting results in conferences and international journals. The academic outputs from this project are listed in Table 2. The publications are available on the NESP Tropical Water Quality Hub website.

Table 1: List of publications

Date	Title	Journal/Conference/Workshop
Apr 2018	Smarter irrigation management in the sugarcane farming system Using the internet of things	Australian Society of Sugar Cane Technologists Conference 2018
Sep 2018	Internet of Things for Smarter Irrigation in Australian Sugarcane	International Sugar Journal
May 2019	Smarter irrigation scheduling in the sugarcane farming system using the Internet of Things	Australian Society of Sugar Cane Technologists Conference 2019
Jun 2019	Smarter irrigation scheduling in the sugarcane farming system using the Internet of Things	International Sugar Journal
Nov 2019	Improving water quality for the Great Barrier Reef and wetlands by better managing irrigation in the sugarcane farming system	Water Quality Synthesis Workshop, Mackay
May 2020	Development of a closed-loop irrigation system for sugarcane farms using the Internet of Things	Computers and Electronics in Agriculture

2.2.6 Seminars

The project team has hosted several seminars to enhance the project's outcomes and deliverables and to discuss other smart technologies that can benefit agro-environmental systems, as listed in Table 2.

Table 2: List of seminars

Date	Speaker	Topic	Location	Attendants
April 2017	Eric Wang	Internet of Things and Agriculture	Burdekin	Project Team Consultative group
Nov 2017	Eric Wang	Wireless Communications for the Internet of Things	Burdekin	Project Team Consultative group
Feb 2018	Wei Xiang	Internet of Things Engineering at JCU	Cairns	Project Team Consultative group, SRA, MSF
Feb 2018	Yvette Everingham	Climate change impacts on sugarcane production in Australia	Cairns	Project Team Consultative group, SRA, MSF

2.3 IrrigWeb

IrrigWeb is a decision support tool for the sugar industry. IrrigWeb uses CANEGRO to provide farmers with current and local advice on sugarcane development and water use for their specific fields, as shown in Figure 4. The tool combines crop water-use estimates with user-defined irrigation system constraints and crop-cycle inputs to schedule future irrigation events. At the initialisation stage, the user must input farm information, such as area, crop class, soil type, row configuration, irrigation management rule, irrigation deficit and harvest date.

IrrigWeb acquires meteorological data daily from a third-party source such as the Queensland Government's SILO application, along with the weather data from local weather stations, and uses the CANEGRO model to calculate crop growth information, such as daily soil water deficit, crop water use, crop stress, biomass, as shown in Figure 5. As for irrigation, IrrigWeb uses soil water deficit and estimated crop water use to provide the amount of water required for each irrigation set, as shown in Figure 6. Farmers can then use this information to plan their irrigation management and apply irrigation schedules to their automated irrigation tools. IrrigWeb can also provide graphical and tabular reports on crop development, including crop stress factor, biomass and yields.

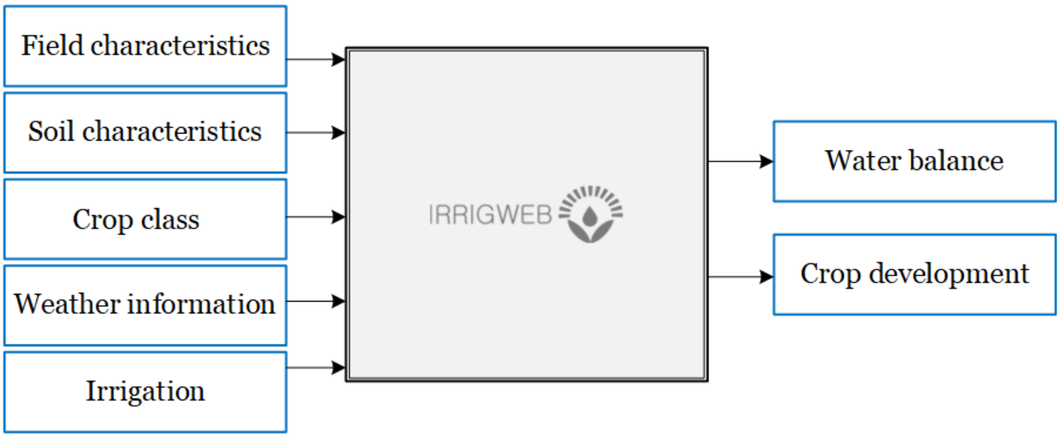

Figure 4: System diagram of IrrigWeb. IrrigWeb takes farm information, i.e. field and soil characteristics, crop class. IrrigWeb calculates crop development information and water balance using daily weather data and irrigation information.

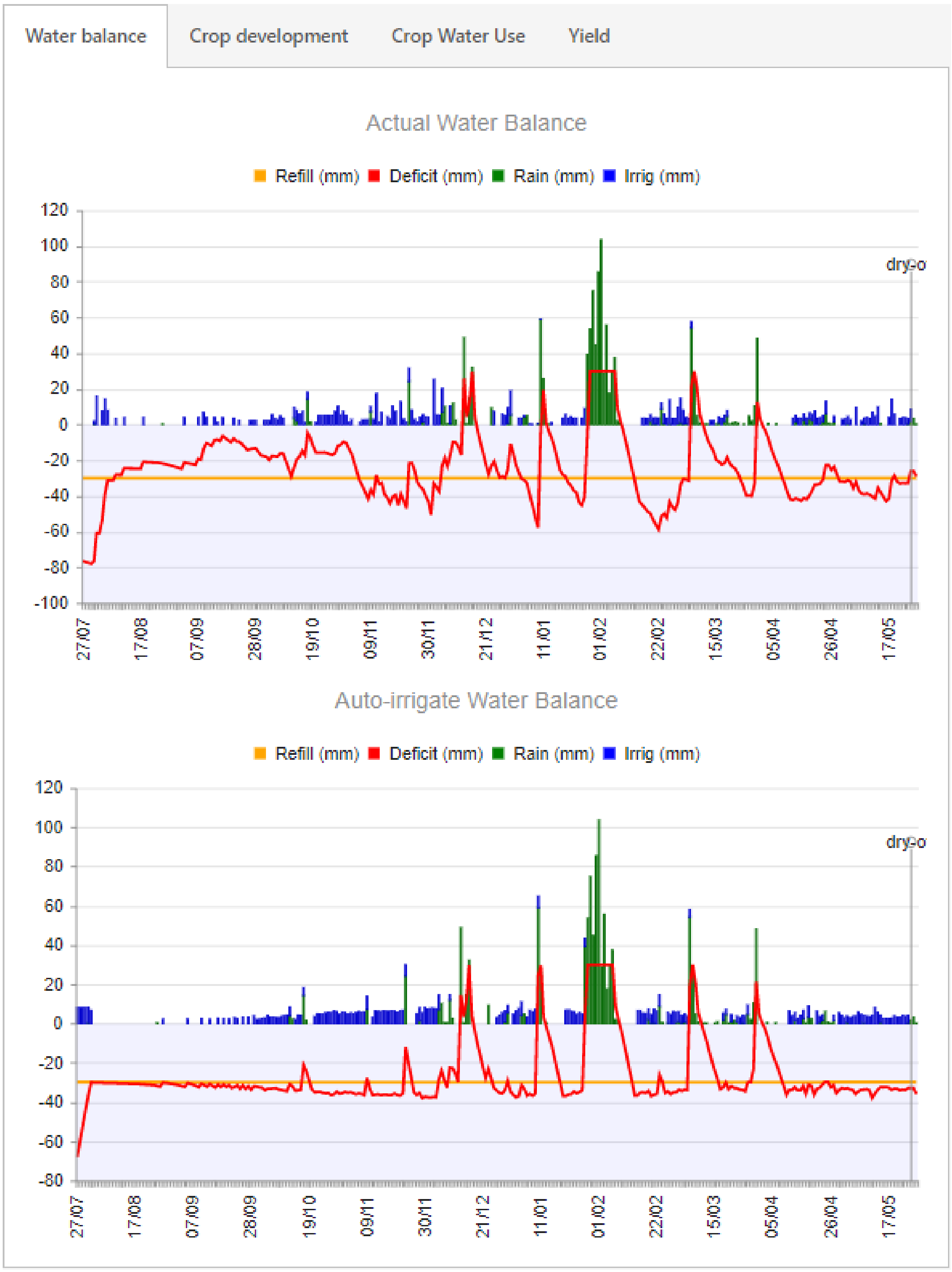

Figure 5: IrrigWeb water balance chart. Refill (mm) is the soil water deficit set up by the farmer to trigger irrigation events for this paddock, Deficit (mm) represents soil water deficit, Rain (mm) is the daily rainfall amount, Irrig (mm) is water applied by each irrigation event. The actual water balance chart on the top shows the water balance from the actual irrigation management by the farmer, and the bottom chart shows the water balance from IrrigWeb simulation with the ideal irrigation schedule.

	Paddock name	Next irrigation date	Soil w... deficit (mm)	Total irrig. (mm)	Total rainfall (mm)	CWU prev. 7 days (...	Cano... prev. 7 days	CWU next 7 days (...	Total i... next 7 days	27 M...	28 M...	29 M...	30 M...	31 M...	1 Jun	2 Jun
	Set 9	27/05/2019	-92.6	624.8	1072.0	16.3	77.6	22.5	80	80						
	Set 3	27/05/2019	-42.1	809.4	1071.5	21.7	88.7	24.2	30	30						
	Set 4	27/05/2019	-71.8	705.9	1071.5	21.5	83.3	23.5	60	30			30			
	Set 1	27/05/2019	-67.5	868.8	1071.5	20.1	79.4	23.9	60	30			30			
	Set 2	27/05/2019	6.4	102.5	26.6	4.1	7.7	11.6	60.5	6...						
	D4	27/05/2019	-0.6	104.8	26.6	6.4	8.7	7.5	1.8	1.8						
	Set 7	27/05/2019	-85.6	0.0	0.0	0		8.2	60	30			30			
	D2	29/05/2019	-25.5	734.0	1071.8	22.5	90.1	24.9	16.5			2.2	3.6	3.6	3.6	3.4
	Set 10	02/06/2019	-38.3	798.9	1072.0	10.6	70	22.3	80							80
	Set 11	02/06/2019	-35.2	755.3	1071.8	7.2	66.7	22.2	80							80
	D3	On Dry-off	-81.4	1080.0	1077.0	22.9	82.9	14								
	D1	On Dry-off	-26.1	754.8	1072.0	22.6	90.4	25								
	Set 6	> next 7 days	-15.1	750.8	1071.5	21.5	86.7	24								
	Set 8	> next 7 days	1.9	150.6	7.8	4.6	0.6	6								

Figure 6: IrrigWeb scheduling. IrrigWeb generates daily irrigation schedules, based on the current soil water balance, the crop water use for the next seven days, and the irrigation management rules.

2.4 Internet of Things

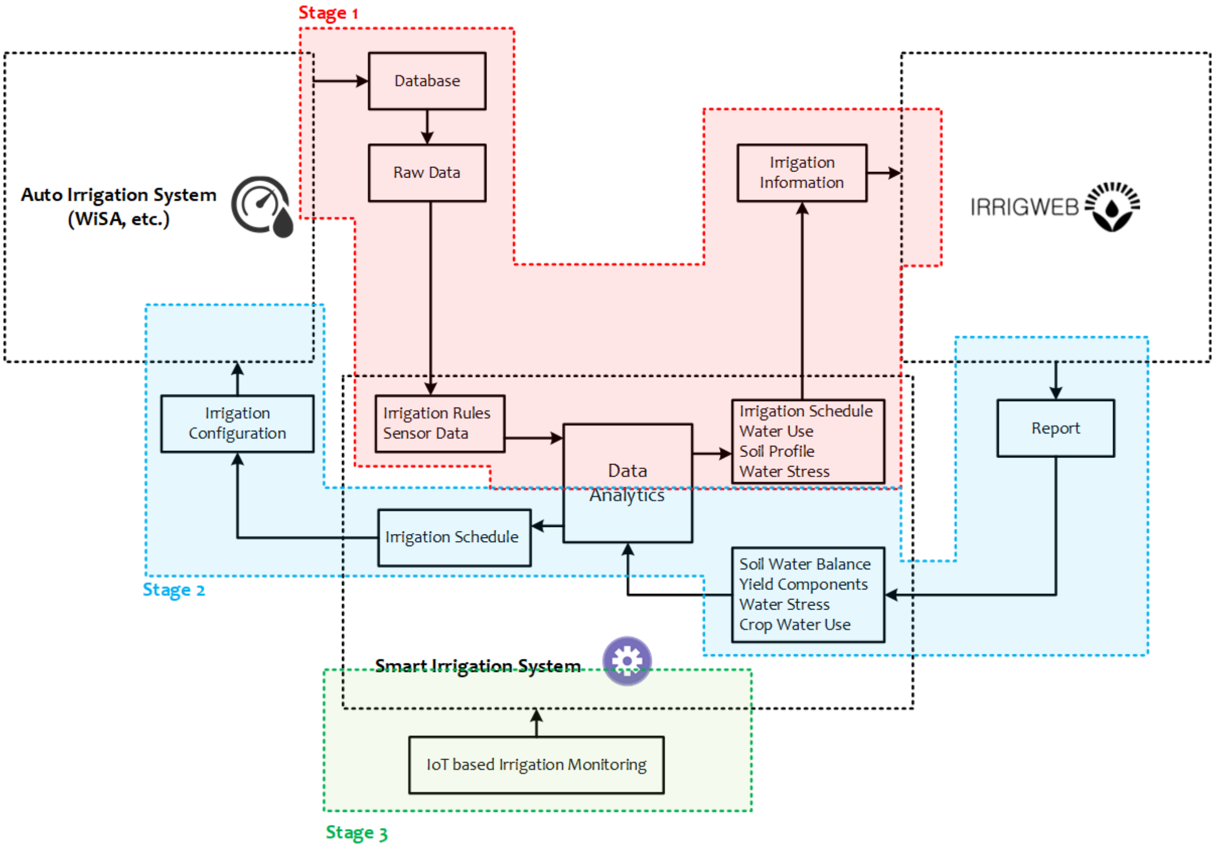

Figure 7: Smarter irrigation system using IoT

The architecture of the *smarter* irrigation system is shown in Figure 7, which consists of three stages:

(i) Stage 1 – auto-irrigation management: an Uplink program (WiSA to IrrigWeb) automatically extracts, calculates and uploads the irrigation and rainfall data from WiSA to IrrigWeb;

(ii) Stage 2 – *smarter* irrigation scheduling: a Downlink program (IrrigWeb to WiSA) automatically exports, converts and applies the optimised irrigation schedule from IrrigWeb to WiSA; and

(iii) Stage 3 – IoT based irrigation monitoring: an IoT based irrigation system monitors the irrigation events happening on the farm, and utilises the data from flow meters, valves and pumps to ensure the operation of the Uplink and Downlink programs.

2.4.1 Uplink

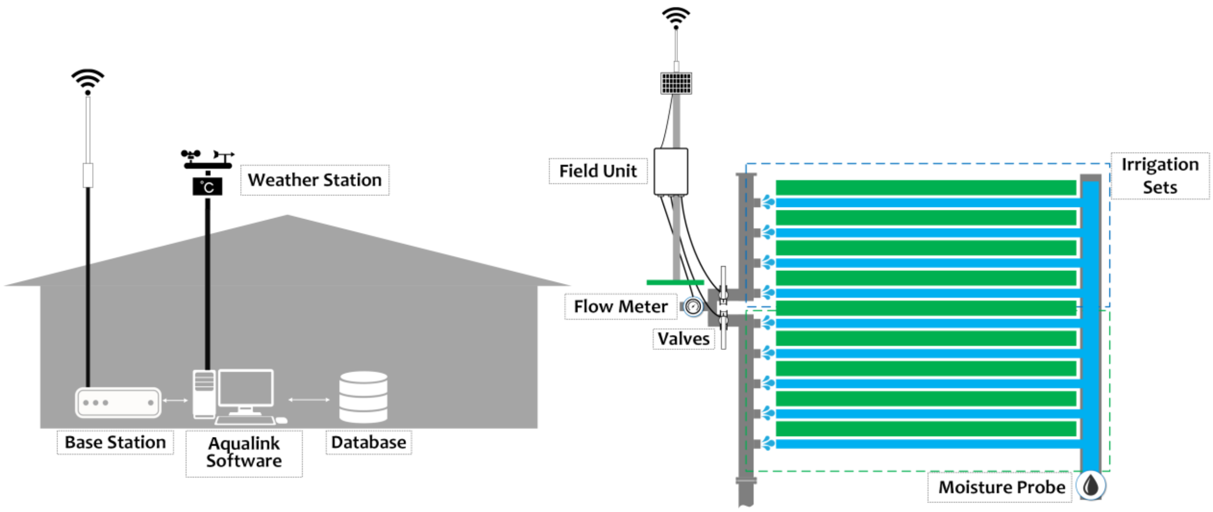

Figure 8: WiSA auto-irrigation system

For the WiSA irrigation system, each farm is divided into multiple irrigation sets, where one or two irrigation sets are connected to one field unit. The WiSA auto-irrigation system uses radio communications to monitor water flow, water pressure, soil moisture and weather information, and control pumps and valves. The framework of a WiSA auto-irrigation system is shown in Figure 8, which consists of:

(i) A base station: it conveys messages between field units and the computer program Aqualink;

(ii) Field units: they a) collect data from the connected sensors, e.g., moisture probes, flow meters and pressure transducers, pack them into messages, and convey these messages to the base station; and b) retrieve the control signal from the base station, and controls on/off of valves and pumps;

(iii) Weather station: it collects weather information (e.g., rainfall, radiation, temperature and rainfall); and

(iv) Aqualink, as shown in Figure 9: it manages data storage and display, and irrigation management.

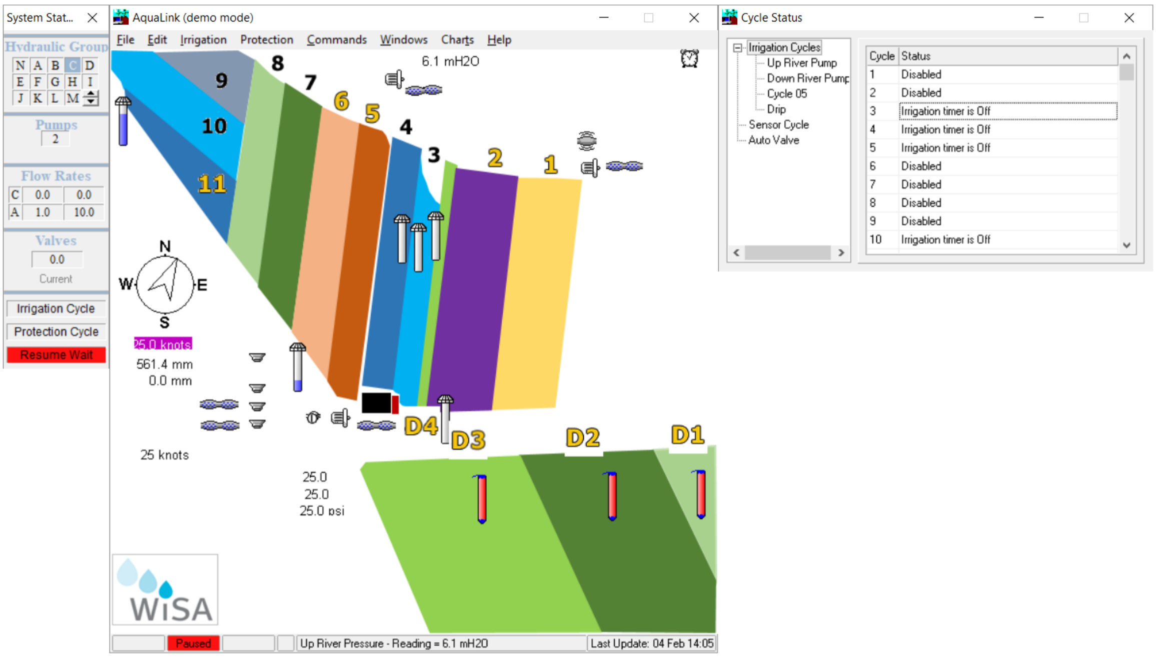

Figure 9: Irrigation management software Aqualink

In the first stage of the project, an Uplink program is designed to connect WiSA with IrrigWeb. The Uplink program can access the database of WiSA irrigation management software (Aqualink) to extract the data entries for all the devices, e.g. pumps, valves, pressure transducers, moisture probes, and flow meters. The program will then use the extracted data to calculate the irrigation data for each irrigation set on the farm, e.g. the irrigation date, mm of water applied, and mm of rainfall received. The resulting data file will then be stored and uploaded to IrrigWeb.

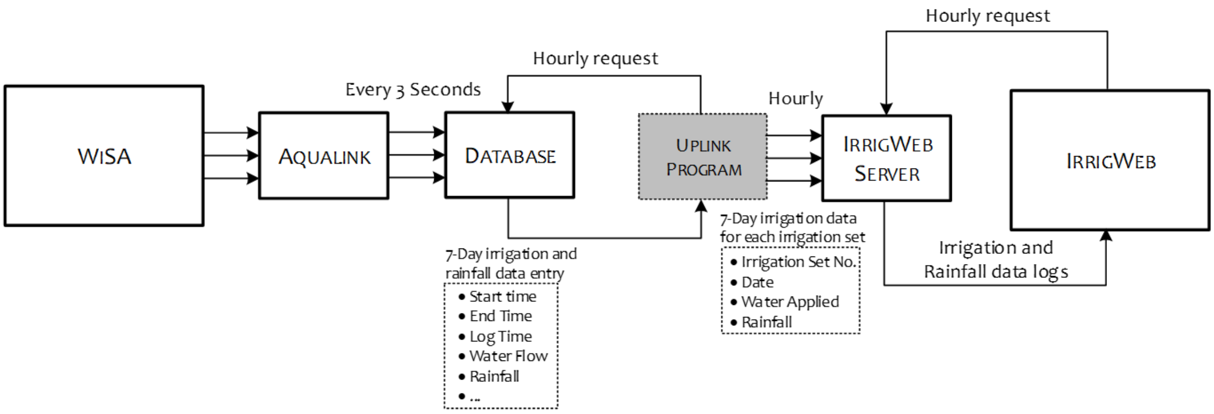

Figure 10: The Uplink program extracts the data entries for all the devices from Aqualink every hour and calculate the irrigation data for each irrigation set on the farm, e.g. the irrigation date, mm of water applied, and mm of rainfall received. The resulting data file will then be stored and uploaded to IrrigWeb.

As shown in Figure 10, the information flow of the Uplink program includes:

1) WiSA passes the data from all the connected devices, including pumps, valves, flow meters, pressure transducers and moisture probes to Aqualink every 3 seconds;

2) Aqualink stores the incoming data from WiSA in a computer database with information, such as a) start and end time for pumps and valves; and b) logging time and value for moisture probes;
3) The Uplink program interrogates the Aqualink database on an hourly basis, extracts the relevant data for each irrigation set, and calculates the irrigation and rainfall information including date, irrigation set ID, mm of water applied, and mm of rainfall each day;
4) The Uplink program uploads the irrigation and rainfall records for the last seven days to an IrrigWeb server on an hourly basis; and
5) IrrigWeb will request the seven-day irrigation and rainfall records on the server and log into each corresponding user's IrrigWeb.

IrrigWeb uses meteorological inputs from a third-party source such as the Queensland Government's Scientific Information for Land Owners (SILO) application, or directly from local weather stations. Different fields or blocks are defined by the user to represent their farms or paddocks. All the fields are assigned with a soil type, a crop class and an irrigation rule. Irrigation inputs are manually captured on a daily basis, and IrrigWeb will use the daily meteorological inputs combined with the irrigation inputs to provide users with a range of graphical and tabular reports, and more importantly, the irrigation schedule for the coming days. Instead of manually logging the daily irrigation data, the developed *smarter* irrigation system will upload the daily irrigation data on an hourly basis to the IrrigWeb server.

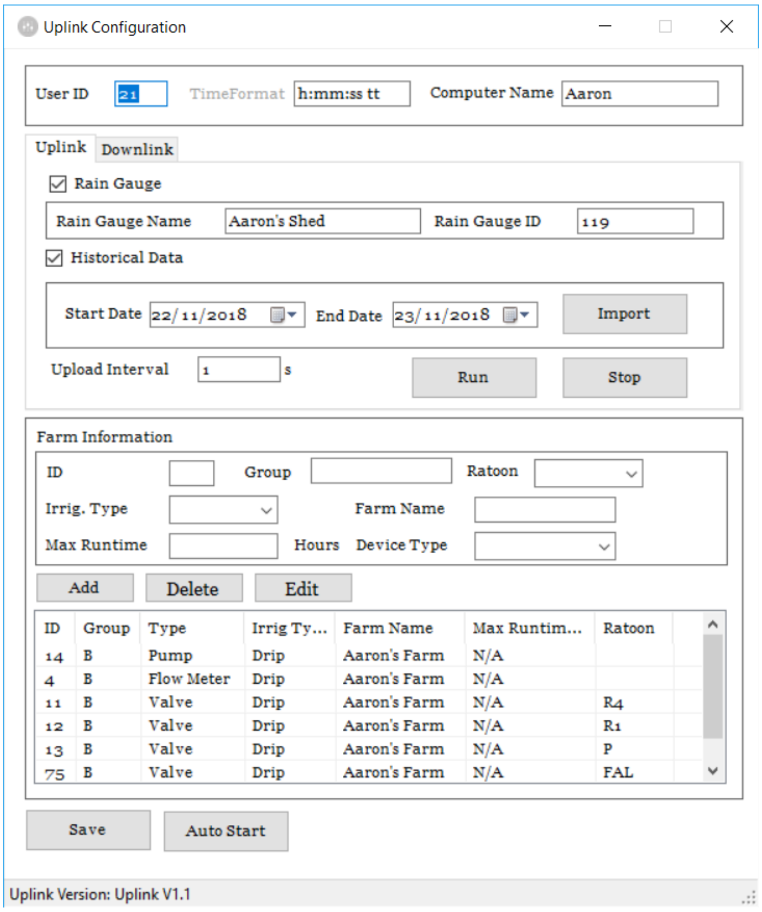

Figure 11: Uplink handover tool, which allows users to easily configure their irrigation system setups, irrigation type, number of hydraulic groups, etc.

A handover tool is developed to easily configure the Uplink program for new farms, which includes setting the farm name, rain gauge information, hydraulic group information (i.e. pump, valves and moisture sensors), as shown in Figure 11. The handover tool with the Uplink user manual (See Appendix 1) is also developed to allow users to import historical irrigation and rainfall data to IrrigWeb easily.

In addition, an uplink monitor was developed as a management tool to monitor the operation status of the Uplink program for all farms. The program will show the last updated time of the Uplink program at the farm and will push a notification or email if the Uplink program has not been updated for more than 24 hours, as shown in Figure 12.

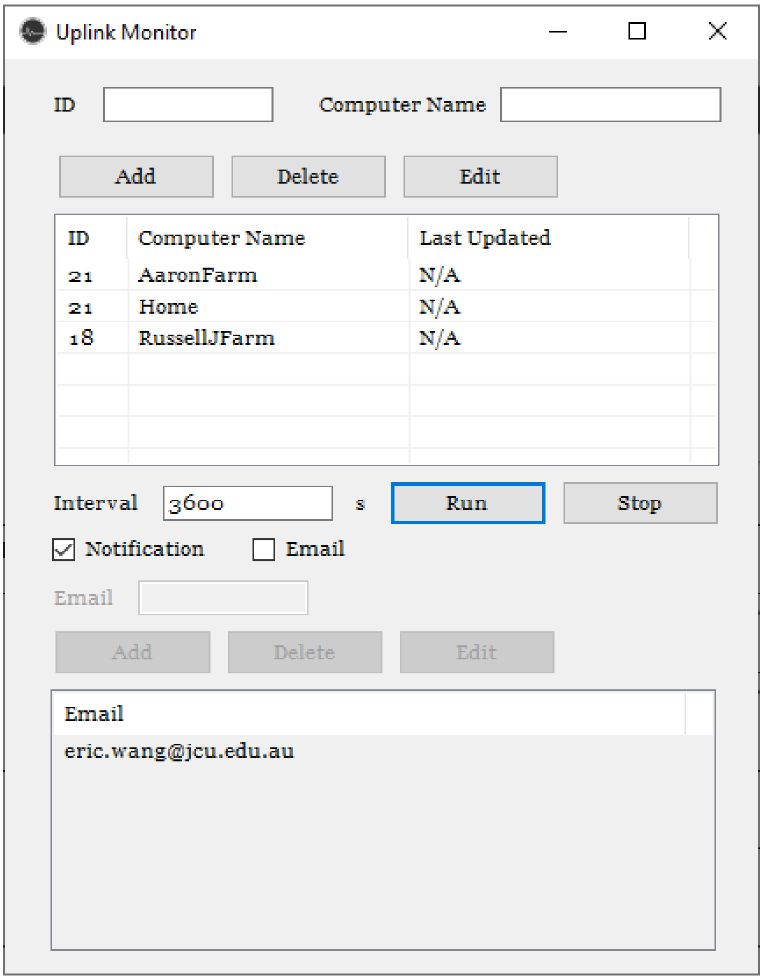

Figure 12: The uplink monitor is a management program (needs to be running on the management team's computer) developed to monitor the operation status of the Uplink program on all the farms.

2.4.2 Downlink

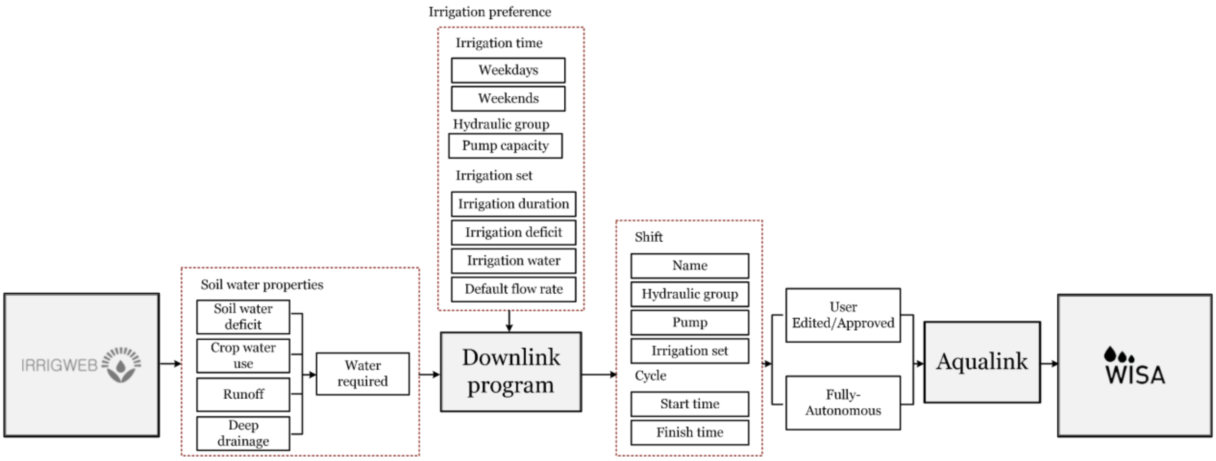

Figure 13: The Downlink program downloads the soil water deficit and daily crop water use from IrrigWeb every hour and calculates the water required for each paddock. Then the Downlink program automatically arranges the irrigation scheduling for each paddock based on any energy constraints, irrigation system limitations and farmer preferences.

The system diagram of the Downlink program is shown in Figure 13. The Downlink program downloads the soil water deficit and daily crop water use from IrrigWeb to calculate the water required for the next irrigation subject to the setup constraints defined by the user. As depicted in the figure, the Downlink program:

(i) Interrogates the IrrigWeb server hourly and downloads the soil water properties for each irrigation set, including soil water deficit (*SWD*), crop water use (*CWU*), runoff (*RO*) and deep drainage (*DD*);

(ii) Combines irrigation time preferences (e.g. off-peak and peak time for weekdays and weekends), pump capacities for each hydraulic group, irrigation characteristics for each set (including duration, SWD deficit threshold, default design flow rate);

(iii) Calculates water deficit for each irrigation set using the formula:

$Downlink\ water\ deficit_{\ of\ today} = (SWD + I + Rainfall - CWU - DD - RO)_{of\ yesterday}$; where I = irrigation applied;

(iv) Determines the irrigation priority ranking based on the calculated Downlink water deficit;

(v) Uses the following formula to calculate the irrigation applied (*I*) required if the *SWD* of an irrigation set passes below the user-defined irrigation deficit threshold (*TH*):

$I_{of\ today}$ (mm) $= TH - Downlink\ water\ deficit_{of\ today}$, if $Downlink\ water\ deficit_{of\ today} < TH$;

(vi) Calculates the irrigation duration for each set based on the obtained *I* required;

(vii) Calculates the irrigation schedule for each irrigation set based on the irrigation time preference, the pump capacity and the irrigation priority ranking;

(viii) Exports the irrigation schedule configuration in the format of the automated irrigation system, e.g. irrigation shifts and cycles for WiSA;

(ix) Updates the irrigation schedule in the automated irrigation system and starts a new irrigation schedule.

2.4.3 Monitoring

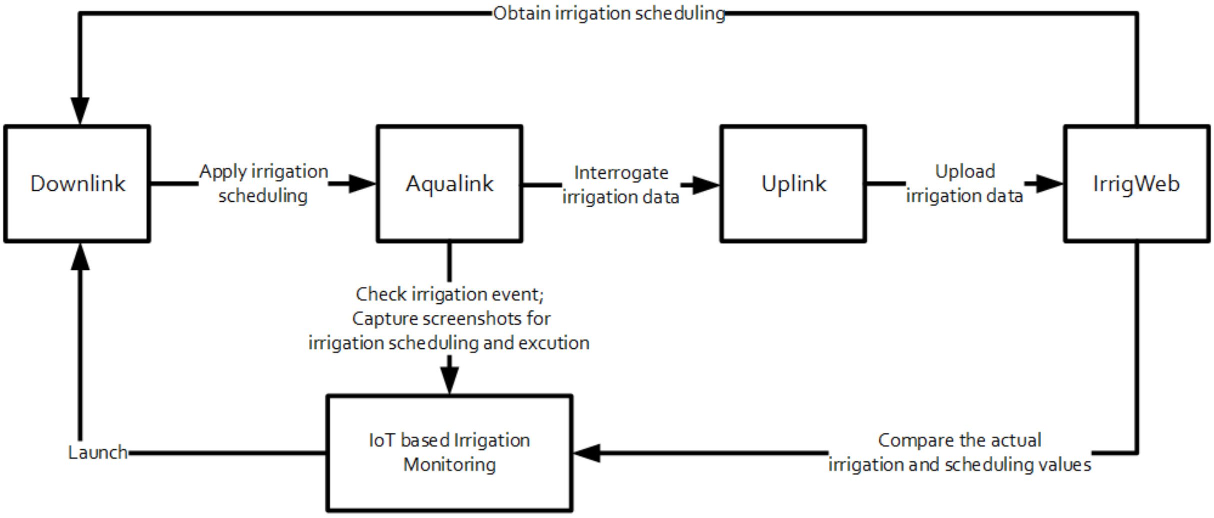

Figure 14: IoT based Irrigation monitoring system

An IoT based irrigation monitoring is developed to ensure the running of the *smarter* irrigation management system. The monitoring system utilises the flow rate information, on/off time of valves and pumps to monitor the running status of the Uplink and Downlink programs. As depicted in Figure 14, the IoT based monitoring works as follows:

(i) At around 7 am when all the irrigation events finish (based on Tariff 62 setup, where the weekday offpeak is from 9pm to 7am, and the weekends offpeak is 24 hours), the system will wake up to check whether there are any irrigation events running at this time. If there is an irrigation event, the program will wake up after an hour and recheck the running status until there is no irrigation event running;

(ii) When there is no irrigation event running, the system will wake up the Downlink program;

(iii) The Downlink program will obtain the scheduling information from IrrigWeb based on the latest irrigation data, and apply the schedule to Aqualink;

(iv) The system will capture multiple screenshots of the status of Aqualink and forward them to farmers to ensure the schedule has been applied successfully;

(v) Five minutes after each irrigation event, the system will take a screenshot for each irrigation event and forward to farmers to ensure the schedule has been executed successfully;

(vi) The Uplink program will calculate and upload irrigation data to IrrigWeb every day based on the latest irrigation event status;

(vii) The next day, after the irrigation event finish, the system will check the irrigation data that has been uploaded by the Uplink program and compare with the irrigation schedule of the Downlink program to make sure the irrigation schedule has been executed successfully.

3.0 KEY RESULTS DISCUSSION

3.1 Successful adoption of Uplink

With the intensive testing performed on the JCU Cairns community garden test farm, the project team made a significant improvement to the Uplink program, which allowed the team to confidently install on one commercial sugarcane farm in the Burdekin region in August 2017. The sugarcane farm setup used to trial the *smarter* irrigation system is shown in Figure 15. This Burdekin sugarcane farm is located near Home Hill and is about 100 ha, and its irrigation system is a combination of both pressurised (sub-surface drip) and furrow irrigation. The 15 paddocks in this farm are divided into three hydraulic groups, with 11 paddocks using furrow irrigation, i.e. the down-river hydraulic group with two paddocks, and the up-river hydraulic group with nine paddocks, and four paddocks using pressurised (drip) irrigation. The test farm has been using the WiSA automated system for more than six years.

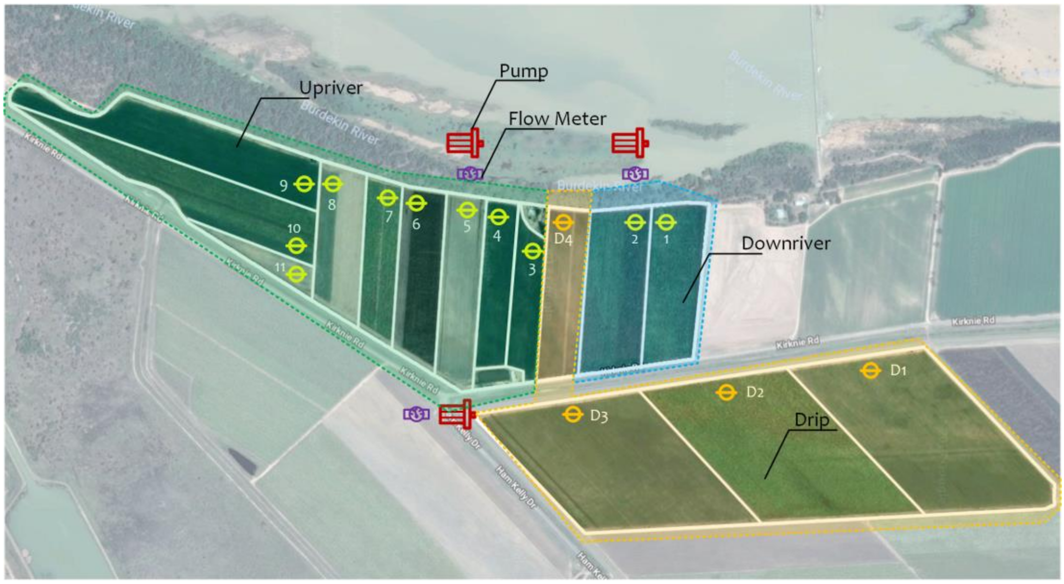

Figure 15: The test farm is divided into three hydraulic groups, i.e., the Upriver and Downriver groups are with furrow irrigation system, and the Drip group is with a drip irrigation system.

During 2017, the Uplink program was developed and successfully deployed on a Burdekin farm, and has been automatically uploading the irrigation and rainfall records to the farmer's IrrigWeb since August. The farmer's irrigation records, i.e. the date and water amount applied to each irrigation set, are automatically loaded into IrrigWeb. The IrrigWeb records for two irrigation sets on the farm are shown in Figure 16 and Figure 17.

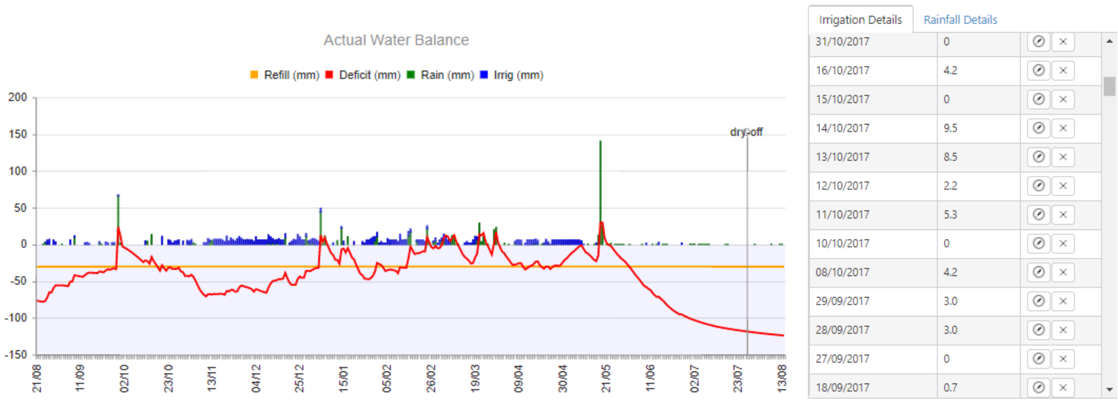

Figure 16: IrrigWeb record (Drip irrigation, 27/10/2016 – 27/10/2017). In the left chart, Refill (mm) is the soil water deficit set up by the farmer to trigger irrigation event for this paddock, Deficit (mm) represents soil water deficit, Rain (mm) is the daily rainfall amount, Irrig (mm) is water applied by each irrigation event. The right table shows an extract of the irrigation and rainfall records of this paddock.

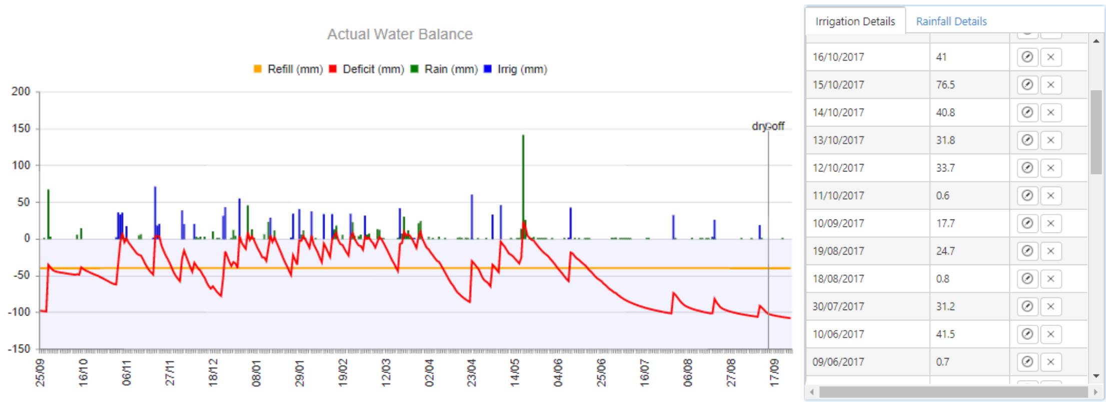

Figure 17: IrrigWeb record (Furrow irrigation, 27/10/2016 – 27/10/2017) .

Our results show there were 1,001 irrigation events and 118 rainfall records between 27/10/2016 – 27/10/2017 for this farm. If it takes the farmer an average of five minutes to manually log on and enter each record, a total of **(1001+118) * 5 = 5595 mins = 93.25** hours would have been needed for the farmer to enter these records for the past year. This presents a significant barrier to the optimal use of technology. The Uplink program overcomes this barrier by saving the farmer a significant amount of time by making the scheduling more efficient. Another benefit is that the farmer can now see the exact amount being applied to each field, and make modifications to their irrigation management if required.

In addition, with the newly developed Uplink handover tool, the project team has also installed WiSA, IrrigWeb and Uplink for three more farmers in the Burdekin region. The developed Uplink monitor was used to monitor the running the Uplink in all these farms closely. The Uplink has been able to save those farmers a significant amount of time in irrigation record-keeping and irrigation data uploading.

3.2 Implementation of Downlink

The historical irrigation data from the test farm is used to evaluate the Downlink program. The IrrigWeb data of this farm, including daily soil water deficit, water applied, crop water use, rainfall and yield, in the year 2018, is used for running the Downlink program scheduling simulation.

Figure 18 shows the soil water deficit (SWD) comparison of the Downlink and IrrigWeb schedules for D1 drip irrigation set. It shows that the SWD curve of the Downlink program is nearly identical to the one of IrrigWeb.

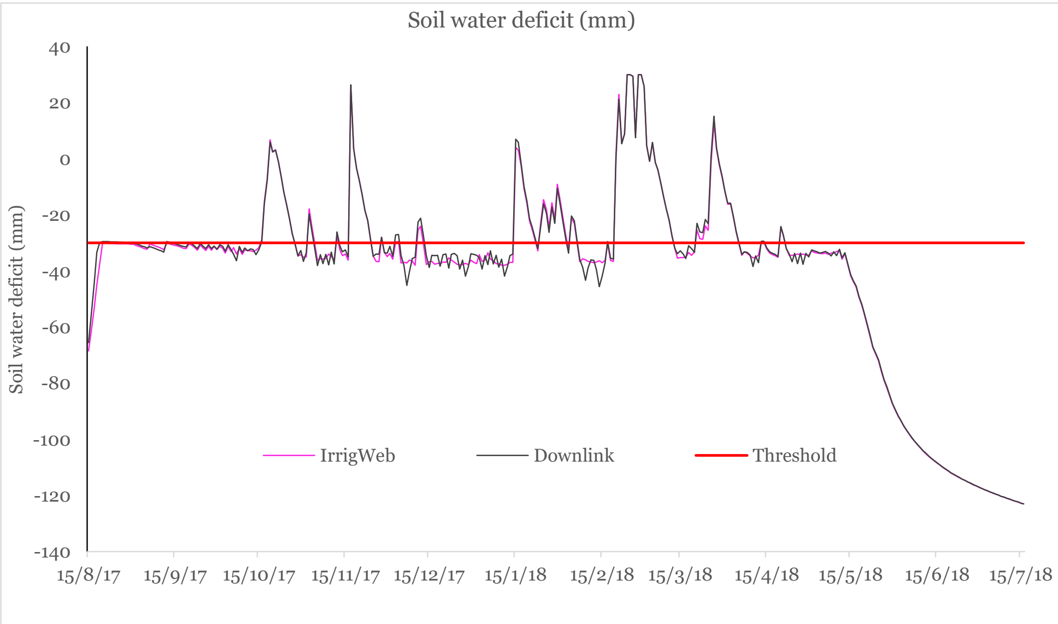

Figure 18: Soil water deficit (SWD) comparison between Downlink and IrrigWeb schedules for one of the drip blocks: D1. Threshold (mm) is the SWD threshold set up by the farmer to trigger irrigation event for this paddock, IrrigWeb (mm) is the SWD of the paddock with IrrigWeb schedules, Downlink (mm) is SWD of the paddock with Downlink generated schedules.

Figure 19 shows the SWD comparison of the Downlink and IrrigWeb schedules for Set 2, a furrow-irrigated field in the down-river hydraulic group. The Downlink program can achieve close results in SWD to IrrigWeb.

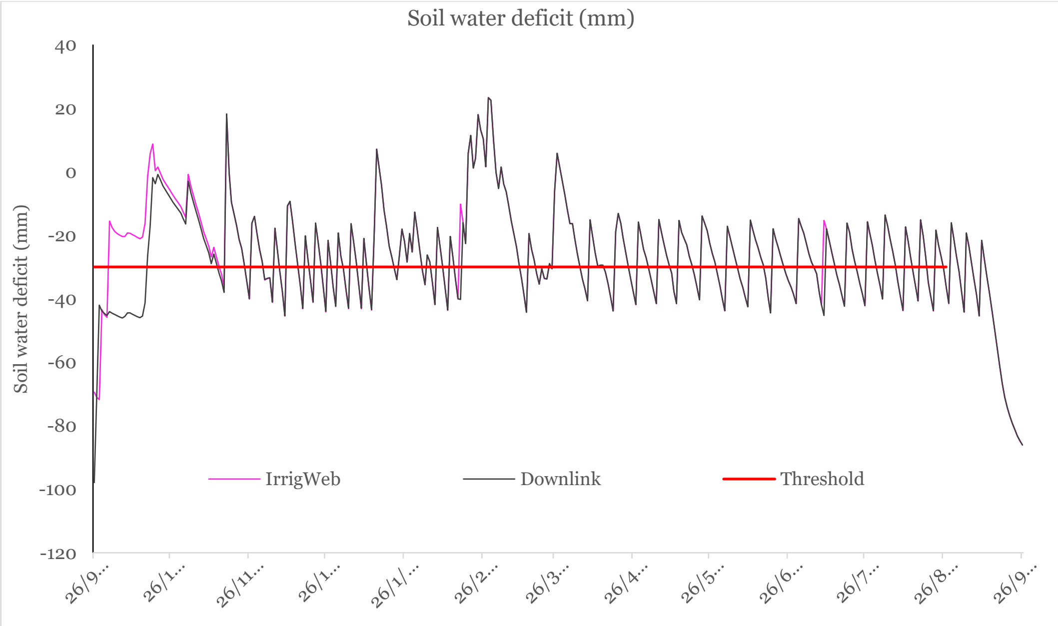

Figure 19: Soil-water deficit comparison between Downlink and IrrigWeb schedules for one of the furrow blocks: Set 2 in the down-river hydraulic group (two paddocks).

Figure 20 shows the SWD comparison of the Downlink and IrrigWeb schedules for Set 8, a furrow-irrigated field in the up-river hydraulic group. The SWD curve of the Downlink program has a drop from 25/12/17 to 20/01/2018, compared to the IrrigWeb SWD curve. There is a significant irrigation demand for all the nine irrigation sets in this hydraulic group , but because of a limited pump capacity, the large number of irrigation sets in this group and the energy constraint (Tariff 62 for this farmer, with 10-hour off-peak time in weekdays), and also the significant crop water use during the period, the requirement to irrigate all nine sets on the same day could not be fulfilled. The Downlink program then creates a schedule that prioritises fields according to irrigation availability. In this situation, Set 8 was not able to be irrigated at the optimum time (i.e. when the irrigation deficit threshold was reached). Therefore, the inadequate irrigation for this set resulted in some crop stresses, which was also observed for some other irrigation sets in this hydraulic group. However, the water balance was improved after a short period when the demand reduced. IrrigWeb calculates a potential crop water use and does not take into consideration the limitation of pumping capacity, and so assumes that each field is irrigated.

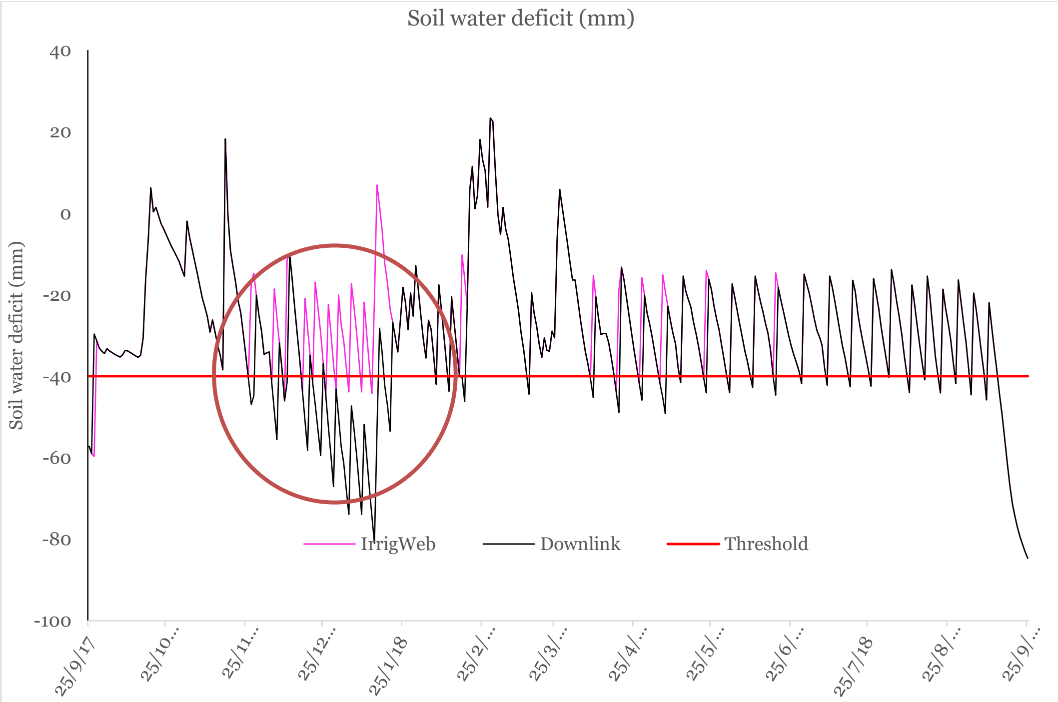

Figure 20: Soil-water deficit comparison among actual, Downlink and IrrigWeb schedules for one of the furrow blocks, Set 8, in the up-river hydraulic group (containing 9 paddocks).

3.3 Farm Trial of the fully automated smarter irrigation system

It has been demonstrated in Section 4.3 that the Downlink program has been able to generate real-time irrigation schedules for each block, including both drip and furrow blocks that mimic the IrrigWeb schedule and incorporate the farmer's irrigation preference, priorities, and tariff constraints.

The purpose of a simulated farm trial is to mimic implementation of the Downlink and Uplink programs in a commercial farm environment, and thus demonstrate the possibility of a closed-loop and fully automated smarter irrigation system, i.e.:

1) The Uplink program extracts, calculates and uploads the irrigation and rainfall data to IrrigWeb;
2) IrrigWeb uses the uploaded data to calculate the soil water deficit and water required for irrigating the next day;
3) The Downlink program downloads the water required data for each paddock and takes into consideration the energy constraint, irrigation system limitation and farmers' preference to calculate the optimised irrigation schedule for each hydraulic group. The Downlink program then applies the irrigation schedule to the automated irrigation system;
4) The automated irrigation system performs the irrigation schedule set by the Downlink program and stores the irrigation data; and
5) Loop back to Step 1.

The simulated farm trial lasted one month from 1st Feb to 1st Mar 2019, and was carried out in two stages:

1. Semi-automated irrigation scheduling (one week)
    a. The Downlink will provide the irrigation schedule daily at 8:20 am.
    b. The schedule from the Downlink program will be first forwarded to both the farmer and project team.
        i. If all three persons all agree on the irrigation schedule, the project team will trigger the Downlink program to apply irrigation schedule to Aqualink;
        ii. If there are any changes from either of the three, The project team will manually modify the irrigation schedule, and then trigger the Downlink program to apply irrigation schedule to Aqualink.
    c. The project team will log onto the farm PC to check if the irrigation schedule has been successfully applied to Aqualink and if the irrigation timer has been triggered.
    d. The project team will check again during the irrigation scheduling timeframe to check if the irrigation schedule has been actuated.
    e. The project team will check the next morning to check if the amount of water applied to each irrigation block are close to the scheduled value.
2. Fully-automated irrigation scheduling (three weeks)
    a. The Downlink will automatically generate and apply the irrigation schedule to Aqualink every day at 8:20 am;
    b. The irrigation monitoring system will send multiple screenshots of the applied schedules and forward to both the farmer and the project team.
    c. The farmer can change the applied irrigation schedule if required.
    d. The irrigation monitoring system will send a screenshot of Aqualink at the start of each irrigation event to both the farmer and project team.
    e. The irrigation monitoring system will check the next day to see if the actual applied water amount is consistent with the schedule.

Table 3 shows the number of irrigation events that the Downlink program has managed during the one month trial. Figures 20 and 21 show the soil water deficit (SWD) and water applied (WA) comparison between using IrrigWeb and Downlink schedules for Drip and Furrow blocks, separately.

Table 3: Irrigation events during the simulated farm trial

Hydraulic group	Block	Number of irrigation events
Drip	D1	14
	D2	14
	D3	14
Downriver	Set 1	3
Upriver	Set 3	3
	Set 4	3
	Set 5	2
	Set 6	3
	Set 9	1
	Set 10	1
	Set 11	1

Figure 21: Soil water deficit (SWD) (mm) and water applied (WA) (mm) of drip blocks, i.e. D1, D2 and D3. The orange line represents the SWD threshold that is set up by the farmer to trigger irrigation events. The blue line represents the SWD using IrrigWeb schedules, and the red line is the SWD using Downlink schedules. The green bar represents the WA using Downlink schedules, and the purple bar is the WA if using IrrigWeb schedules.

It is shown in Figure 20 that the SWD of D2 and D3 using Downlink schedules are nearly identical to that using IrrigWeb schedules. The two SWD curves of D1 deviated a little bit from February 19 to February 22, which is due to the energy usage constraint, set by the farmer, and a sudden high irrigation demand for all three blocks due to an earlier rainfall event. Since D1 is the oldest crop class, it was set as a lower priority. Downlink took D2 and D3 as the priority at this event, and scheduled irrigation for those two blocks, causing the decreasing of the SWD for D1. However, it is shown that the irrigation for D1 was then caught up after February 22.

Figure 22: Soil water deficit (SWD) (mm) and water applied (WA) (mm) of furrow blocks, i.e., Set 3, Set 4, Set 5, Set 6, Set 9, Set 10 and Set 11. The orange line represents the SWD threshold that is set up by the farmer to trigger irrigation events. The blue line represents the SWD using IrrigWeb schedules, and the red line is the SWD using Downlink schedules. The green bar represents the WA using Downlink schedules, and the purple bar is the WA if using IrrigWeb schedules.

It is shown in Figure 22 that the SWD of Set 3, Set 4, Set 5 and Set 6 using Downlink schedules are nearly identical to that using IrrigWeb schedules. The two SWD curves of Set 9, Set 10 and Set 11 deviated a little bit from February 19 to February 22, which is due to the energy constraint and sudden high irrigation demand for all seven blocks due to an earlier rainfall event. Set 9, Set 10 and Set 11 are large paddocks which require more hours for each irrigation event, so the Downlink prioritised the irrigation for other small blocks during weekdays, and irrigate these three blocks during weekends after February 22.

3.4 Adoption of the fully automated smarter irrigation system

With the success of the initial one-month farm trial of the fully automated smarter irrigation system, the project team and participated farmer decided to adopt the fully automated smarter irrigation system for his four drip irrigation blocks. The fully automated smarter irrigation system has been running on the farm since April 2019 for more than a year. The water balance for paddock D3, which was under fully automated smarter irrigation for the whole growing season is shown in Figure 23. Due to some practical incidents, e.g., power outage, water shortage, harvesting and planting, the farmer had to cancel some irrigation events manually, which resulted in the unmatched irrigation schedules between the Downlink and IrrigWeb. However, as shown in Table 4, the water uses and predicted yields using these two schedules are almost identical with negligible differences. It is demonstrated that the smarter irrigation system developed in this project can closely follow the IrrigWeb schedule by including the practical constraints.

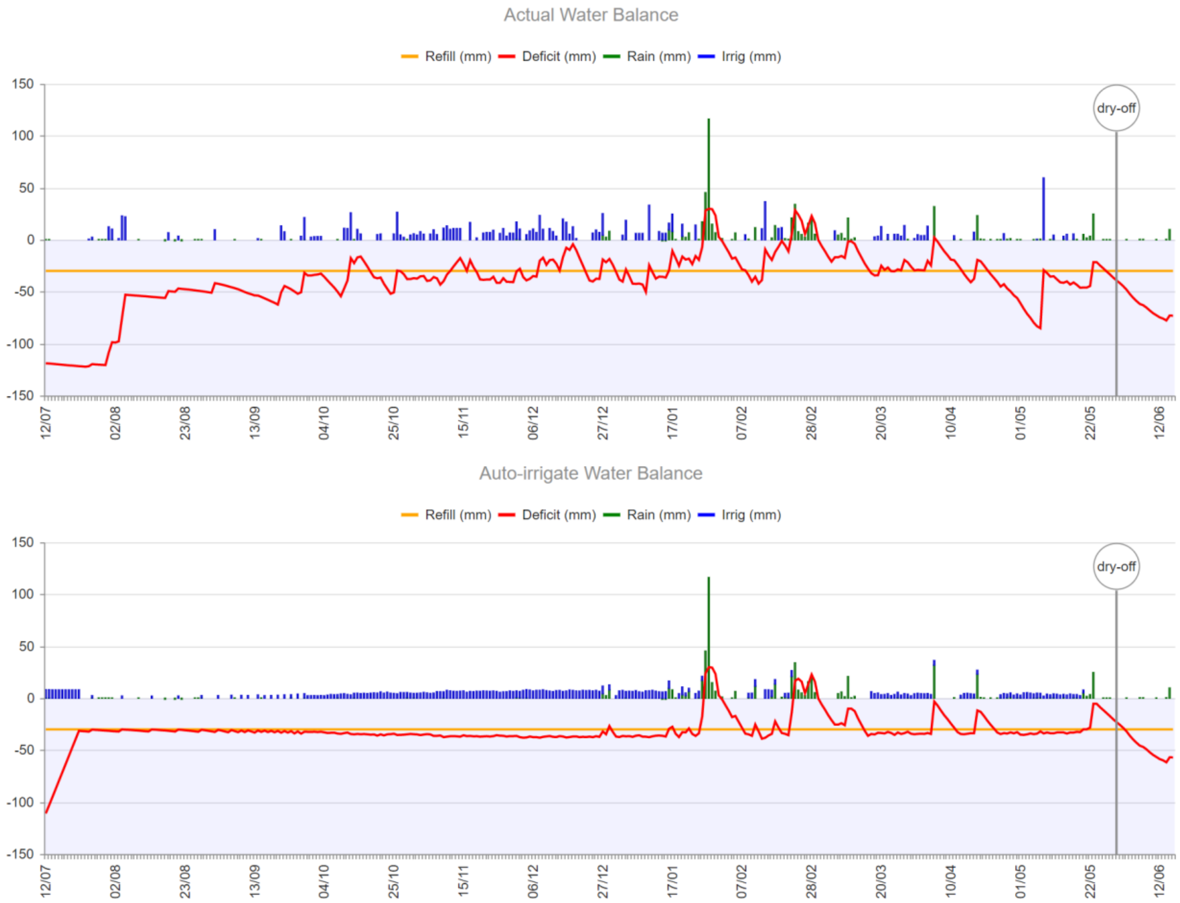

Figure 23: Water balance for D3 in growing season 2020

Table 4: Water use and predicted yield comparison of IrrigWeb and smarter irrigation scheduling

	Water use (ML/ha)	Predicted Yield (t/ha)
Smarter Irrigation	10.6	138.2
IrrigWeb	10.46	140

3.5 Estimating Water Quality Benefits

The Paddock-to-Reef (P2R) program developed the P2R Projector (https://p2rprojector.net.au/) that estimates the improvement in key WQ parameters, i.e. sediment, nutrient (N) and pesticide, that result from on-farm management practice changes. Estimates of management change are driven by the modelling approach developed by the Queensland Government Office of the Great Barrier Reef's (OGBR) 'Paddock to Reef modelling program'.

As an additional achievement to the project, the P2R Projector was used to estimate the improved WQ benefit associated with smarter irrigation practices identified in this project. Specifically, improved irrigation management (e.g. measuring the volume of irrigation water applied with each irrigation, automation, and estimating daily crop water use using tools like

IrrigWeb) was compared to typical practices associated with current furrow irrigation management (e.g. no measurement of applied irrigation volumes, manual operation and management, not using irrigation scheduling tools). Using a range of scenarios, the Projector estimated a range of DIN improvements from 4.8 kg N/ha/year up to 28 kg N/ha/year. With approximately 80,000 ha under sugarcane production, the Projector indicates annual potential benefits of between 384 to 2,240 tonnes of N. This would indicate that smarter irrigation practices will make significant inroads to meeting the Burdekin sugarcane region's DIN reduction target of 720 t/year (Waterhouse, Attard, Rickert, Buono, & Hunt, 2018).

4.0 CONCLUSION

There is an urgent, pressing and unequivocal need, to help Burdekin canegrowers achieve best management irrigation practices, so they can deliver improved water quality outcomes. The Burdekin is the highest sugarcane producing region in Australia. The Burdekin thrives on high radiation levels, low levels of rainfall, and high amounts of water availability for irrigation.

Unfortunately, due to the excess runoff and deep drainage from low-efficiency furrow irrigation systems, the Burdekin sugarcane industry has been identified as a high or very high priority for DIN management, and pesticides identified as a very high priority (Waterhouse et al., 2018). This excess runoff and deep drainage can increase erosion, impede catchment restoration and slow down reef restoration.

The answers to “How much water does that crop need?” … and, “When should it be applied?”, are vital to improving water quality leaving the farm and ensuring the sustainability of the Great Barrier Reef, its lagoons and its catchments. However, these two questions must be complemented with a third, equally important, question….”How can I do this in a practical and effortless way?”.

This project designed, tested and implemented a *smarter* irrigation system to apply the right amount of water at the right time in a practical and effortless way through the integration of automation with an irrigation decision support system using IoT technologies.

4.1 The Smarter irrigation management tool

In the first stage of this project, an Uplink program was developed to automatically log the irrigation and rainfall data to IrrigWeb, from the WiSA irrigation system. The results showed that a significant amount of time had been saved via this process.

In the second stage of this project, a Downlink program was developed to connect IrrigWeb to WiSA, which can download, extract, calculate and apply irrigation schedules automatically. The Downlink program successfully mimics the IrrigWeb generated soil-water deficit for all fields. The Downlink program improves scheduling by incorporating practical limitations, such as pumping capacity or pumping time constraints, that are found on the farm. The Downlink-generated schedule is more life-like and realistic than the IrrigWeb generated schedule. The simulation results demonstrated the potential for significant economic benefits to the farmer in yield increase, while generating savings in water and energy costs.

Combining the Uplink and Downlink programs, the *smarter* irrigation management platform provided an innovative and working solution to the questions “How much water does that crop need?” … and, “When should it be applied?” and “How can I do this in a practical and effortless way?”.

4.2 Identify pathways for wider adoption.

The success and benefits of the Uplink program have captured the attention of many farmers in the Burdekin. There is a growing demand from industry to implement the Uplink program on more farms. Increasing the number of farmers who meet, or exceed, industry best practice irrigation management, will make significant contributions toward meeting the Reef 2050 WQIP targets. To this end, a 'train-the-trainer' model in the installation and testing of the Uplink program in the Burdekin presents a plausible pathway to wider adoption and builds regional capacity to ensure the project outputs are easily accessed after the project finish date. Negotiations to implement the train-the-trainer model in the use of this technology are currently being pursued. Although proof-of-concept was achieved with both the Uplink and Downlink programs, as the Downlink program was being developed later in this project, it requires further testing under more constraints before it is ready to be developed into a handover tool. It is also recommended that farmers consult with an advisor to ensure that IrrigWeb is effectively implemented for their farming system.

4.3 Water quality outcomes

Nutrients, pesticides and sediments are the main catchment runoff pollutants that affect water quality on the Great Barrier Reef. The Reef receives run-off from 35 major catchments that drain 424,000 square kilometres of coastal Queensland. The area of sugarcane in the Burdekin region is approximately 91,000 hectares (91 square kilometres), with approximately 80,000 hectares under production. The dominant water quality issues from the sugarcane area in the Lower Burdekin are DIN and pesticides. For DIN losses, the highest risk is to freshwater systems in the dry season from irrigation runoff and first flush rain events, and to coastal and inner shelf marine ecosystems in periods of high flow. Analysis of paddock scale monitoring and modelling data indicates that a larger proportion of DIN loss occurs via excess irrigation in the Lower Burdekin area. Excess irrigation is lost, via runoff and/or deep drainage, from each irrigation from a majority of the area in the sugarcane cropping area. There is a need to improve irrigation efficiency, which implies reductions in the excess amount of irrigation lost to runoff and/or deep drainage whilst maintaining crop production levels. Matching irrigation application as closely as possible to crop water requirements will minimize excess irrigation.

The Burdekin WQIP (2018) defined several management action targets that are needed to deliver improved water quality. Specifically, it calls for at least 60 per cent of sugarcane areas to be managed using high efficiency irrigation techniques, which it refers to as "B class practices" by 2025. In 2016, less than 20 per cent of growers were B-class (Waterhouse, Attard, Rickert, Buono, & Hunt, 2018) so to meet these targets by 2025 will require large scale implementation of new and novel irrigation management practices.

As described in the 2017 Scientific Consensus Statement (State of Queensland, 2017), modelled management practice adoption scenarios indicate that it will be challenging to meet the 2025 targets with the current suite of agricultural management practices across the GBR catchments.

Automation of irrigation systems (Gillies, Attard, Jaramillo, Davis, & Foley, 2017) is a good start in that it sets the infrastructure up for large scale and efficient changes to management practices. But automation alone, does not guarantee irrigators will apply the correct amount of irrigation, with farmers either irrigating too much or too litte. An irrigation decision support tool like IrrigWeb is needed to optimise the irrigation use efficiency. However, the manual entry of data into IrrigWeb is recognised as a significant barrier to increased adoption of these smart tools. This project successfully demonstrated proof-of-concept of an efficient and effortless data transfer system between the two smart tools; i.e. between IrrigWeb and the WiSA irrigation automation software, removing the need for the farmer to manually enter information. This automated data exchange process will reduce the time imposed on a farmer considerably. The ability to automatically transfer information between independent, smart decision support tools, reduces the barriers to adoption and improves the chance of long-term adoption. Moreover, preliminary modelling using the Paddock-to-Reef projection model, estimates that these technologies can make significant inroads to meeting the Burdekin sugarcane region's DIN reduction target of 720 t/year (Waterhouse et al 2018).

4.4 Final Remarks

The NESP TWQ Hub Project 3.1.2 *smarter* irrigation system represents a solution to saving energy and improving water quality by transferring more farmers to B class practices. Moreover this solution is farmer friendly in that it will save farmers time and money. It also allows farmers to keep better irrigation records enabling them to assess their improved irrigation performance.

Despite these benefits there will still be some barriers to wider adoption. Besides trusting new technologies, another major barrier is the perceived large capital outlay to purchase the infrastructure. Opportunities for incentive programs to make this transition easier and less riskier for producers should be explored.

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APPENDIX 1: UPLINK USER MANUAL

Uplink User Manual V1.1

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Version	Changelogs
1.1	Add configuration of the calculation using either default pump flow rate or default valve flow rate.

The Uplink program is designed to create a connection between WiSA and IrrigWeb and aims to extract the irrigation and rainfall data from Aqualink to IrrigWeb. The basic workflow of Uplink is 1) Extract pump, valve and flow meter data from the Aqualink database for the selected timeframe; 2) Based on the valve operation data, e.g., how many valves are operating at what time and for how long; 3) Take the flow meter readings and assign each opened valve with right amount of water flow under different operating status; 4) Calculate the amount of water applied for each valve during the selected timeframe; and 5) Save and upload the irrigation data to the IrrigWeb FTP server.

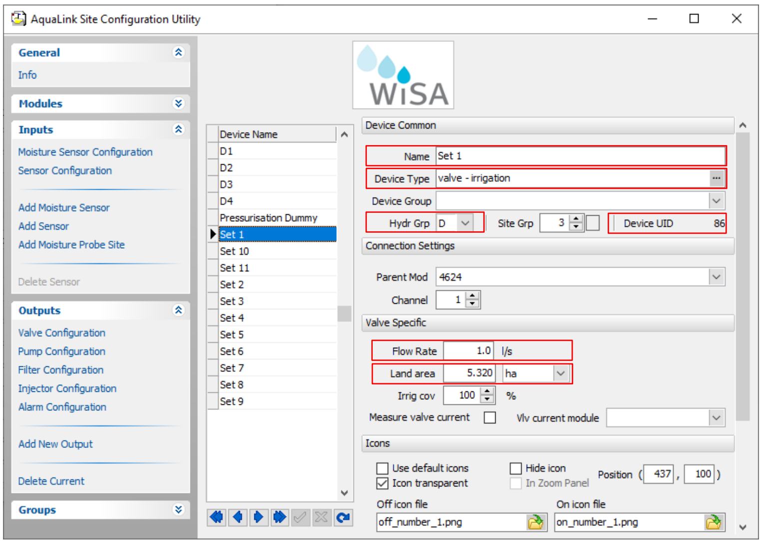
PREREQUISITES

.Net Framework

The Uplink program only works for the Windows operating system. Microsoft .net framework is required to run the Uplink program. Please download and install the Microsoft .net framework from the link below:
https://dotnet.microsoft.com/download/dotnet-framework/net48

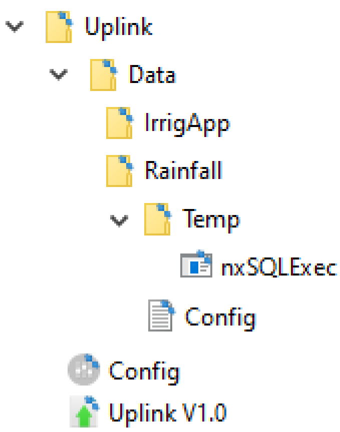
Aqualink

The uplink program relies on the Aqualink database to obtain irrigation and rainfall data. The device properties used by Uplink program are Hydraulic group, Device UID, Device Type, Name, Flow rate, Land Area, as highlighted in the figure below.



INSTALLATION

The current version of the Uplink program is Uplink V1.0. Please download the latest version of the Uplink program from
https://www.dropbox.com/sh/7w6ynd07x0qwva6/AAAjc8TF6b-aAA59yrMS1chVa?dl=0
Please make sure you have download and extract all the files from the link, as shown in the figure below.

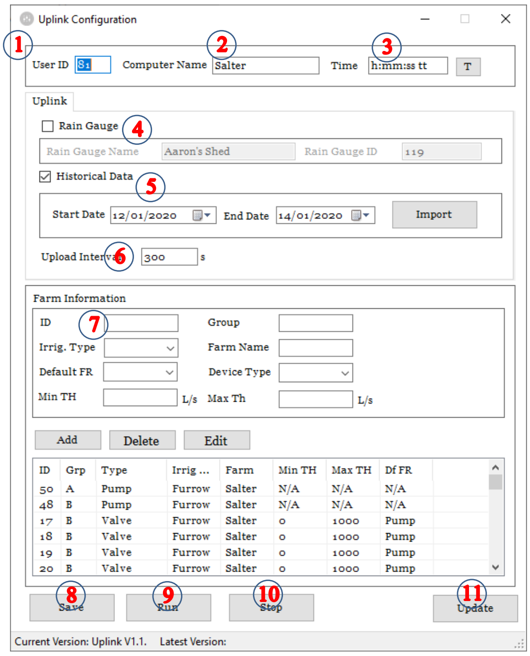


SOFTWARE UPDATE

The Config program for the Uplink program will automatically check the latest version and notify you to update the program.

UPLINK CONFIGURATION

The uplink program has to be configured via the Uplink Configuration program before the operation. Please use "Config.exe" to configure and run the Uplink program, as shown in the figure below.



1. User ID: this is a unique IrrigWeb identifier for each farmer;
2. Computer name: please input a unique name that is different from the farm's name (do not include any symbols in the name);
3. Time format: this is critical to calculate the water volume for each irrigation event. Please make sure it is configured correctly. Click the "T" button to automatically set up time format the first time you run the configuration program. Please refer to the table below for the time format;

"h"	The hour, using a 12-hour clock from 1 to 12.
"hh"	The hour, using a 12-hour clock from 01 to 12.
"H"	The hour, using a 24-hour clock from 0 to 23.
"HH"	The hour, using a 24-hour clock from 00 to 23.
"m"	The minute, from 0 through 59.
"mm"	The minute, from 00 through 59.
"s"	The second, from 0 through 59.
"ss"	The second, from 00 through 59.
"tt"	The AM/PM designator.

4. Rain gauge: tick the checkbox if the farm has a rain gauge, and set the rain gauge UID and name;
5. Historical data import: this function is to import historical data, choose the start and finish time and click the import button to import historical data, the result will be automatically opened and uploaded to the FTP server named 21~xxxxhis.dat;
6. Update interval: Uplink upload interval in seconds;
7. Farm information:
    a. ID: is the device UID;
    b. Group: is the group ID, e.g., A, B, C, D;
    c. Irrig. Type: is Drip or Furrow irrigation;
    d. Farm name: is different from the computer name, in case there are multiple farms running on the same computer;
    e. Device Type: choose from Pump, flow meter and valve;
    f. Min. and Max. Threshold: this is to set the flow meter abnormal alarm. If flow meter readings are outside of the range, the Uplink program will trigger an email alert;

g. Default FR: Default flow rate for calculation, choose between default pump flow or default valve flow;
h. Add button: is used to add a device;
i. Double click a row in the table to edit the device and click the Edit button when finishing edit;
j. Delete button: is used to delete an existing device from the table;

8. The Save button is used to save the configuration;
9. The Run button is to run Uplink
10. The stop button is to stop Uplink
11. The Update button is used to update the Uplink program

UPLINK WORKFLOW

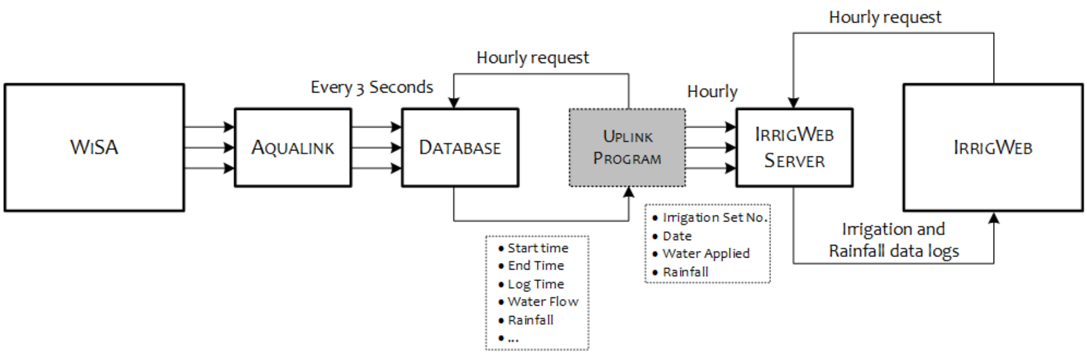


Figure 24 Uplink

The workflow for Uplink is as follows (with the red text representing how Uplink interacts with Aqualink, the green text representing how Uplink processes the data from Aqualink, and the blue text resenting how Uplink interacts with IrrigWeb):

1. Read a configuration file, with the information including the number of hydraulic groups, and information for each hydraulic group, including irrigation type, pump, flow meter and valve IDs.
2. Use "*nxSQLExec*" to query Aqualink database "*ALConfig/Devices*" to obtain the information for each valve, including valve name (*DeviceN*), group ID (*HydGrp*), area (*LandArea*), design flow rate (*MinFlowRate/MaxFlowRate*), etc.
3. Use flow meter and valve IDs (*UID*) to query Aqualink database "*ALData/Outputlogs and ALData/SensorLogs*" to obtain the data within the query time frame (e.g., 01/04/2018 – 07/04/2018) for each hydraulic group, including the log time (*LogDT*) and log value (*SValue*) of the flow meter, and the start time (*StartDT*) and end time (*FinishDT*) of the valves.
4. Calculate the individual flow rate for each irrigation set at each log time:
    a. For drip sets, $f_i = f_M \frac{fs_i}{\sum_i fs_i}$ (litre/second), where f_i is the individual flow rate for valve i, fs_i is the design flow rate of valve i, f_M is the flow rate of flow meter at this log time, and $\sum_i fs_i$ is the sum of the design flow rate of all the valves that are opened at this log time.
    b. For furrow sets, $f_i = f_M \frac{A_i}{\sum_i A_i}$ (litre/second), where A_i (ha) is the area of the irrigation set i.
5. Calculate the irrigation water amount for each set,
    a. For the hydraulic group with a flow meter, $W_i = \sum_{t_s<t<t_e}(f_{i_t} \times I_t)$ (litre), where W_i is the water amount, f_{i_t} is the flow rate for valve i at time t

between the start time t_s and end time t_e, and I_t is the time interval for each flow rate log (e.g., 300 seconds or 180 seconds).

b. For the hydraulic group without a flow meter, $W_i = \sum_{t_s<t<t_e}(fs_i \times I_t)$ (litre).

6. Calculate the water applied, $wa_i = \frac{W_i}{A_i \times 10000}$ (mm).
7. The water applied for each irrigation set during the last 7-day is calculated and saved into a file named "*Famer ID~Farm name*.dat", with the following format:

Name,Date,Block,Water Applied (mm)
Home,05/02/2018,D2,6.91
Home,05/02/2018,D1,6.91
Home,05/02/2018,D3,5.31
Home,05/02/2018,D4,5.31
Home,05/02/2018,D5,0.00
Home,04/02/2018,D2,12.68
Home,04/02/2018,D1,12.68
Home,04/02/2018,D3,13.54
Home,04/02/2018,D4,13.54
Home,04/02/2018,D5,0.00
Home,03/02/2018,D2,16.70
Home,03/02/2018,D1,16.70
Home,03/02/2018,D3,13.82
Home,03/02/2018,D4,13.82
Home,03/02/2018,D5,0.00

8. The file is uploaded to IrrigWeb FTP server folder "*/IrrgApp*".
9. IrrigWeb server interrogates the FTP folder every hour and updates the irrigation data for each farmer.

WATER APPLIED CALCULATION

The amount of water applied to each irrigation block can be calculated as *the recorded flow rate on the valve flow meter multiplied by the recording interval then multiplied by the number of records*. Since in the test farm, there are no flow meters at each valve, the flow rate for each valve can be approximated to be proportional to the area.

Mathematically, we can generalise the calculation of the amount of water applied and develop an algorithm to implement this calculation in the Uplink program. Let $T_{i,n} \in \{T_{i,1}, T_{i,2}, \dots, T_{i,N} | i \in \{1, I\}, n \in \{1, N\}\}$ and $F_{i,n} \in \{F_{i,1}, F_{i,2}, \dots, F_{i,N} | i \in \{1, I\}, n \in \{1, N\}\}$ be the timestamp and flow rate for the n^th^ record of flow meter i, where I is the total number of flow meters in the hydraulic group, and N is the total number of records for flow meter i. Defined by $T^S_{j,m} \in \{T^S_{j,1}, T^S_{j,2}, \dots, T^S_{j,M} | j \in \{1, J\}, m \in \{1, M\}\}$ and $T^F_{j,m} \in \{T^F_{j,1}, T^F_{j,2}, \dots, T^F_{j,M} | j \in \{1, J\}, m \in \{1, M\}\}$ the start time and finish time for the m^th^ irrigation event of valve j in one day, where J is the total number of irrigation blocks, and M is the total number of irrigation events for valve j. Here, the normalised flow rate for record $\tilde{F}_{i,n}$ is defined as the recorded flow rate divided by the sum of areas A_j of irrigation blocks j opened at this timestamp, represented as follows:

$$\tilde{F}_{i,n} = \frac{F_{i,n}}{\sum_{j \in J_O} A_j} \text{ (litre/second/ha)}, \quad J_O = \{\text{j} | T^S_{j,m} < T_{i,n} < T^F_{j,m}\}$$

The total amount of water applied (litre) in one irrigation event $W_{j,m}$ for an irrigation block can be calculated as the summation of the normalised recorded flow rate which satisfies $T_{i,n} \in \{T^S_{j,m}, T^F_{j,m}\}$ multiplied by the recording interval (which is set to 5 minutes in Aqualink), then multiplied by the area of irrigation block j, which can be represented as:

$$W_{j,m} = A_j \sum_{i=1}^{I} \left(\sum_{n=1}^{N} \tilde{F}_{i,n} \times 300 \right) \text{ (litre)}$$

while the timestamp $T_{i,n}$ of each normalised flow rate record $\tilde{F}_{i,n}$ is within $\{T^S_{j,m}, T^F_{j,m}\}$. Thus, the total amount of water applied (mm) for irrigation block j in one day can be calculated as:

$$W_j = \sum_{m}^{M} \frac{W_{j,m}}{10000 A_j} \text{ (mm)}$$

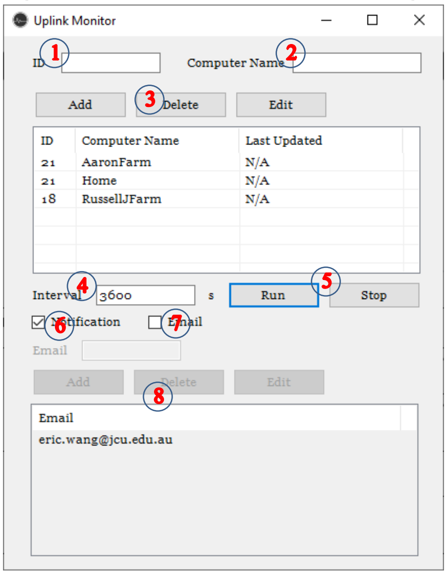
Please refer to the table below for the water applied calculation for different irrigation scenarios.

Table 5 Water applied calculation for different scenarios (litre)

Irrigation scenarios		With flow meter	Without flow meter
Single pump	Only on valve opened	Actual flow rate * duration	Default flow rate * duration
	Multiple valve opened	Actual flow rate * duration * (block area/total area)	Default flow rate * duration
Multiple pumps	Only on valve opened	Actual total flow rate * duration	Default flow rate * duration
	Multiple valve opened	Actual total flow rate * duration * (block area/total area)	Default flow rate * duration

UPLINK MONITOR V1.0

The uplink monitor is a management program (needs to be running on the management team's computer) developed to monitor the operation status of the Uplink program in all the farms. The program will show the last updated time of the Uplink program at the farm and will push a notification or email if the Uplink program has not been updated for more than 24 hours. The Uplink monitor program can be download from the link below.
https://www.dropbox.com/sh/k4v5ucti7j12t1s/AABuHh5OIgnn9X1NpI4BjmTNa?dl=0
The use of this program is straightforward, as shown in the figure below.



1. ID: the IrrigWeb ID for the farmer;
2. Computer Name: should be identical to the name setup in Uplink;
3. Add, delete and Edit buttons are used to add, delete and edit the farm information on the table;
4. Interval: is to set up how often the Uplink monitor check the Uplink program on each computer;
5. Run and Stop button are used to start and stop the monitor;
6. Tick the notification checkbox to enable notification on the computer;
7. Tick the Email checkbox to enable sending an alert email to all the email addresses in the table below;
8. Add, delete and edit buttons are used to add, delete and edit the email addresses on the table;

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