University of Southern Queensland

School of Engineering

Surface Irrigation Variability Analysis and Modelling using Advance Furrow Sensors

A dissertation submitted by

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in fulfillment of the requirements of

ENP4111 Professional Engineer Research Project

towards the degree of

Bachelor of Agricultural Engineering (Honours)

2024

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University of Southern Queensland

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ENP4111 Dissertation Project

(This is a 2-unit research project in Bachelor of Engineering Honours Program)

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CERTIFICATION

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ABSTRACT

This research project investigates the impact of soil compaction on surface irrigation performance with the aim to enhance irrigation efficiency in Australian agriculture. It was observed through the reviewing of literature that many farms experience high degrees of compaction variability and that irrigation modelling software's have not been used to address this issue. The study utilizes a Surface Irrigation Simulation, Calibration and Optimisation (SISCO) tool to assist in the analysis of field variability. The project involved collaborations with the Centre for Agricultural Engineering employing a current advance moisture sensor design to provide data in real time on an irrigation event for calibrating soil infiltration parameters in SISCO.

The field trials were conducted at Struanville Farming Co in South-east Queensland where furrows of variable compaction were analyzed. Particularly tramlines, normal/uncompacted and planting track furrows were monitored to assess the intensity of infiltration and runoff that occurred. SISCO individual furrow simulations revealed that higher compacted furrows had significantly reduced infiltration and higher runoff, which thereby lowered application efficiency. Three separate strategies were compared with the assistance of SISCO multi furrow analysis. It was found that the third irrigation proposal, which had an optimised duration and flow rate increased the application efficiency by over 20% when compared to the actual event achieving a peak application efficiency of 75.57%.

The study findings confirm that adjusting irrigation strategies based on the level of compaction can yield substantial improvement to the irrigation performance. The project provides a framework for more sustainable irrigation practices within Australia that promotes higher crop yields, reduced water wastage and improved soil health.

ACKNOWLEDGEMENTS

This research project has been intensely supported by many different people, organisations and groups. First and foremost, I would like to express gratitude to my supervisor, Dr Malcolm Gillies, whose expertise has been employed throughout the research journey. They have given oversight and guidance providing insightful feedback to shape this dissertation. I also acknowledge the Centre for Agricultural Engineering (CAE) at UniSQ and staff for their assistance in the usage of their resources and facilities particularly for allowing the physical testing to take place. More specifically Associate Professor Joe Foley and Dr Simon Kelderman at the CAE. They have assisted in the sourcing of a research farm and in the development of the advance moisture sensor. They have provided valuable guidance in the direction of the dissertation and are a contributing factor to the overall success.

Outside of the university I would like to acknowledge Struanville Farming Co, who were happy to oversee the research being conducted on the property. Specifically, Glen Biggs was a point of contact for the farm, who facilitated in communications between myself and the farm management team. They provided myself with the required location and irrigation requirements to readily get data for the purpose of this dissertation.

There are many crucial influences both named and unnamed, who impacted greatly to the success of this research project and for that I acknowledge their contributions.

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GLOSSARY

Advance Wave: The movement of water as it progresses down a furrow in a surface irrigation system.

Application Efficiency (AE or Ea): The ratio of water volume stored in the root zone to the total volume of water applied, usually expressed as a percentage to measure irrigation efficiency.

Calibration: The process of adjusting infiltration parameters to align with the observed field data using an irrigation modelling software.

Centre for Agricultural Engineering (CAE): A research institution based at the University of Southern Queensland, Australia.

Cracking Soil: A type of soil, often clay based that forms cracks when dry.

Deep Percolation: The downward movement of water through the soil profile beyond the root zone.

Distribution Uniformity (DU): A measure of how evenly water infiltrates across an irrigation event, expressed as a ratio of average infiltration depth in lowest quarter to overall average infiltration depth.

Field Variability: Differences in soil, compaction, moisture and slope that occur within a singular agricultural field.

Flow Rate: The volume of water supplied per unit of time to an irrigation event generally in litres per second (L/s).

Furrow Irrigation: A type of surface irrigation where water is guided through small, parallel channels between crops.

Hydraulic Head: The height difference between two bodies of water which drives water movement in irrigation systems.

Hydraulic Modelling: The simulating of water movement through fields or irrigation channels through equations.

Infiltration Rate: The speed at which water enters and moves through the soil profile.

IPARM: A hydraulic modelling tool that uses volume-balance and empirical methods to estimate irrigation infiltration.

Mannings Number (n): A roughness coefficient used in hydraulics to model flow resistance in open channels.

Optimisation: The process of adjusting irrigation parameters to achieve highest possible efficiency and best performance.

Plant Available Water Capacity (PAWC); The volume of water in the soil that is accessible for plant uptake.

Pressurised Irrigation Systems: Systems that use mechanical pumps to force water through irrigation lines to water crops.

Requirement Efficiency (RE): A measure of how effectively an irrigation system meets the water need for a crop. It is calculated as a ratio of the water volume that infiltrates into the root zone to the total volume of water required by the crop.

Root Zone: The soil layer that holds the majority of plant roots where water is required for the crop to grow.

Runoff: Water that flows off the field surface without infiltrating, being collected in the tail drain.

SIRMOD: A software tool for simulating surface irrigation events.

Surface Irrigation Simulation, Calibration and Optimisation (SISCO): A hydraulic modelling software to simulate and optimise surface irrigation events.

Taggle System: A brand of system that is used to transmit information from a field to a central location.

Time to Cut-off (Tco): The specific time in which water supply to the irrigation system is stopped.

Tramline: Compact pathway created by the repeated traffic of agricultural machinery.

Water Holding Capacity: The maximum volume of water that soil can retain before excess water drains away.

Wilting Point: The soil moisture level at which plant can no longer extract the sufficient amount of water causing the plant to stress and wilt.

WinSRFR: An irrigation modelling software tool developed by United States Department of Agriculture.

CHAPTER 1 INTRODUCTION

1.1 OVERVIEW

The agricultural industry must further evolve and adapt in order to meet the global food production requirements in the future decades. Furthermore, the industry must achieve food security with sustainable and regenerative practices for the sake of the precious natural resources and environment as a whole. It is predicted that up to 590 Million hectares of irrigated agriculture will be required to feed the global population in 2050 (Kelly, 2020). Innovative solutions are imperative to progress the agricultural industry forward, with the ultimate goal surround increasing efficiency, profitability and sustainability. Research will be of particular importance to the ensure that Australia's most precious resource water is used effectively and sustainably.

1.2 PROBLEM/NEED FOR RESEARCH

Currently agricultural irrigation is responsible for the usage of 70% of all freshwater withdrawals globally, with research suggesting that only one half of the irrigation water used is directly reusable (Kelly, 2020). In 2020-2021 Australian irrigated crops and pastures consumed 7.8 Million megalitres across 1.9 Million hectares (ABS, 2022). Surface irrigation is the most widely adopted method in Australia with it accounting for around 59 percent of total irrigation land (Koech and Langat, 2018). The efficiency of these surface irrigation systems averages around 60 percent which ultimately suggests that 40 percent of the water applied in this method is escaping through deep percolation and water runoff (Taghvaeian, 2017). There are many factors that can affect the efficiency of this operation, they include, soil type, topography, climate and water quality. An increase to the efficiency rate will allow producers to save on labour requirements, water conveyance costs and furthermore reduce the leaching of essential nutrients from the field. One of the largest contributing factors to the inefficiency of surface irrigation is the lack of technological usage to assist the farmer in recognising when the water has reached the optimum depth. This research project is designed to recognise the field variability and provide recommendations to minimise the overuse of precious water resources.

1.3 KNOWLEDGE GAP

Prior research has been undertaken around different irrigation systems with better efficiency and improved control of application rates. The most relevant alternative for cropping industries in Australia are centre pivot and lateral move machines. These centre/lateral pivot and drip irrigation systems are quite simply not an affordable or viable alternative for all farmers and thus the surface irrigation is still important to agricultural food and fibre production. There are a range of potential improvements/recommendations available to increase the surface irrigation efficiency including the integrating of sensors with smart watering systems. They employ key parameters like ground slope angle, soil texture and water flow rate to optimise the irrigation performance (Taghvaeian, 2017). These factors whilst helpful do not eliminate the potential human error in over irrigating and the potential for field variability. Research conducted in 2015 covers the development of a surface irrigation tool known as SISCO (or Surface Irrigation Simulation, Calibration and Optimisation) tool that can assist in maximising the efficiency of surface irrigation systems (Gillies and Smith). The research surrounding this software has been continued with the Centre for Agricultural Engineering (CAE) at the University of Southern Queensland Toowoomba campus. These tools however do not adequately resolve the issues around the spatial variability of water movement across the field. The knowledge gap is proven to exist with the project aiming to utilise surface irrigation software and advance moisture sensors to quantify the effects of field variability on irrigation performance.

1.4 AIM

The proposed dissertation is aimed at investigating and analysing the field variability within a surface irrigation system. The goal will be to identify how to maximise efficiency, sustainability and profitability simultaneously to combat the rising demand for global agricultural production.

1.5 OBJECTIVES

There are 5 main objectives of this project are:

1. **Research -** Conduct background research into surface irrigation and what the specific aims and objectives are for farmers.
2. **Selection of Surface Irrigation Simulating Software –** Evaluate different irrigation modelling software to select the most suitable and accurate for field testing.
3. **Sensor Familiarisation and Preliminary Testing –** Acquire/build sensors for irrigation purposes and perform small testing to provide groundwork for field trials.
4. **Irrigation Event and Data Extraction –** Run an irrigation event with equipment setup to extract and record data from the field location.
5. **Analysis and Evaluation of Data using SISCO –** Process results with SISCO to then be analysed and compared across the different sensor locations.

1.6 OUTLINE OF DISSERTATION

This project intends to complete the objectives outlined above to successfully identify and analyse spatial variability specifically regarding compaction within a surface irrigation system. The data will be extracted from field trials during the same event and evaluated with assistance from a surface irrigation modelling program. The expected outcomes from this research project is as follows:

- To have gained greater understanding surrounding irrigation systems in agriculture.
- To have utilised sensors to measure and record water movement during a surface irrigation event.
- To acquire greater insight into the impact of compaction on irrigation performance.
- To be able to recommend or propose how a farmer can optimise their water efficiency.

The project is aimed at completing the expected outcomes throughout this report. This includes the following chapters:

1. Introduction
2. Background and Literature Review
3. Development of Advance Furrows Sensors
4. Field Methodology
5. Field Trial Data
6. SISCO Data Modelling
7. Optimised Irrigation Proposal
8. Conclusion

These chapters will provide a thorough overview of the entire project from start to finish with a final analysis and presentation of the key findings from all testing that is completed.

CHAPTER 2 BACKGROUND AND LITERATURE REVIEW

2.1 AUSTRALIA IRRIGATION TRENDS

The vast and evolving landscape of Australia is considered to be one of the driest inhabited continents, despite its large footprint in the global food and fibre production. As a result, Australia is facing increasing pressure to manage the most precious resource of water for agricultural production. As mentioned previously there is over 1.9 Million hectares of irrigated land consuming around 7.8 Million megalitres annually (ABS,2022). With irrigation alive and well in Australia it will be evermore important to adopt precision irrigation technology and tools to ultimately maintain productivity and sustainability.

A 2015 report conducted by Koech, Smith and Gillies (2015) investigated the trends associated with Australian surface irrigation. More specifically the authors were interested in the role that surface irrigation will play for the future agricultural crop production. This involved utilising data from the Australian Bureau of Statistics (ABS) analysing the water and land usages over the previous decades. The project explores surface irrigation methods specifically as they are generally simple to operate and have low energy and capital requirements. Surface irrigation is considered to be a less efficient irrigation method when compared to pressurised systems. Historically during the late 1990's surface irrigated cotton in Queensland would yield between 17% and 100% in efficiency, averaging at 48% (Koech, Smith & Gillies 2015). This was recently found in another study to have increased to an average of 64.6% which is still considered to be relatively wasteful (Roth et al., 2013). Despite these statistics the study investigated if surface irrigation practices are still crucial to Australian agriculture and why they have not been superseded by more advanced pressurised systems. The report also aims to investigate the improvements made to irrigation practices both physically through infrastructure advances and management related from computer simulating software and real time optimising technology. This has been a contributing factor to the increasing efficiency rate in this form of irrigation however the authors still believe that farmers could be improving this to consistently within the range of 85% to 95% (Koech, Smith & Gillies 2015).

The methodology of the research was comparatively straightforward using published agricultural surveys from the ABS and the United States Department of Commerce as the primary data source. The data was taken from the decades before 2015, particularly focusing on the water usage and the percentage of total irrigated land for each of the different application methods. Depicted below in Figure 2.1 is the total irrigation water usage of Australia between 2002 and 2014. This data was extrapolated by the authors to present a graphical representation of the variation to establish if irrigation as a whole is still a major contributor for Australian agricultural production. From the data collected it can be determined that the early 2000's water usage by agriculture averaged just over 10,000 gigalitres per season. This number dramatically dropped between 2006 and 2012 to as little as 6,500 gigalitres annually. This figure fluctuates according to water availability and was 9,981 GL in 2021-2022 (ABS 2023). Koech, Smith and Gillies (2015) cross referenced the drop in irrigation water usage with Australian weather patterns to find a potential reason for the data anomaly between 2006 and 2012. It was found that a severe drought across the entire Murray Darling Basin (MDB) was the cause of the drastically reduced water availability (Koech, Smith & Gillies 2015). This is supported from the fact that the MDB accounts to two-thirds of Australia's Irrigation water usage (Gibson, 2024). Thus, the information in figure 1 denotes water availability and usage for irrigation will be relatively similar in the future years to come with exclusions for weather or climate abnormalities.

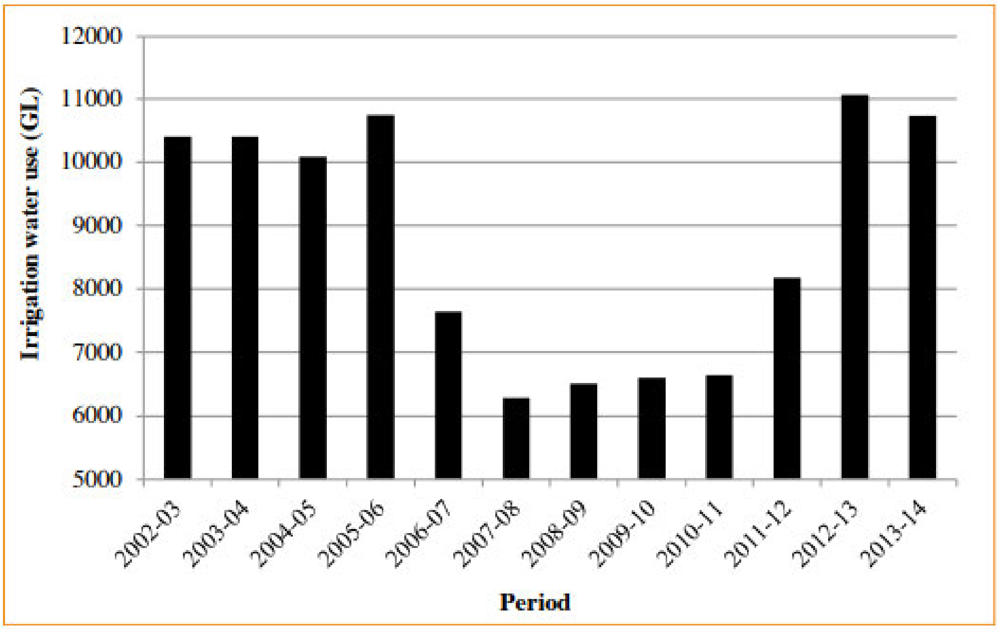

Figure 2.1 Total Irrigation Water Usage in Australia from 2002 to 2014 (Koech, Smith & Gillies 2015).

Koech, Smith and Gillies (2015) also graphically represented total area of irrigated land in Australia and the percentage of each irrigation method used as shown in Figure 2.2. Data is available for the proportion using Surface, Drip/Trickle, Sprinkler and Other irrigation. The data appears to support the general trend from figure 2.1 which suggests a drought event affected the irrigated crop production during the period of 2006 to 2012. It does however demonstrate a similar total area of irrigated land from the early 2000's to the year 2014 of approximately 2.3 million hectares. The main observed difference over this time period is the application system used. Originally in the 1990's, surface irrigation accounted for approximately 74% of all techniques employed. The research from 2014 now suggests that there has been a 15 percent decline in the portion of Australian land that uses surface irrigation (Koech, Smith & Gillies 2015). The authors have found that surface irrigation remains the primary method utilised in Australia occupying 59% of the total irrigated land. The trend suggests that the adoption of sprinkler irrigation systems is rising causing a drop in the percentage of land with surface irrigation. Data from the United States has also supported this with a higher adoption rate of sprinklers. The drought period interestingly brought about a peak in the usage of sprinkler systems. This is due to the system being a more effective and efficient method of water application, specifically in times of water scarcity. This has potentially triggered the shift of Australian irrigation with a special focus on water saving. Whilst it is still one of the most inefficient methods of irrigation currently, there is still evidence to support that with water availability and future advancements, farmers will continue to adopt this cost effective method of irrigation.

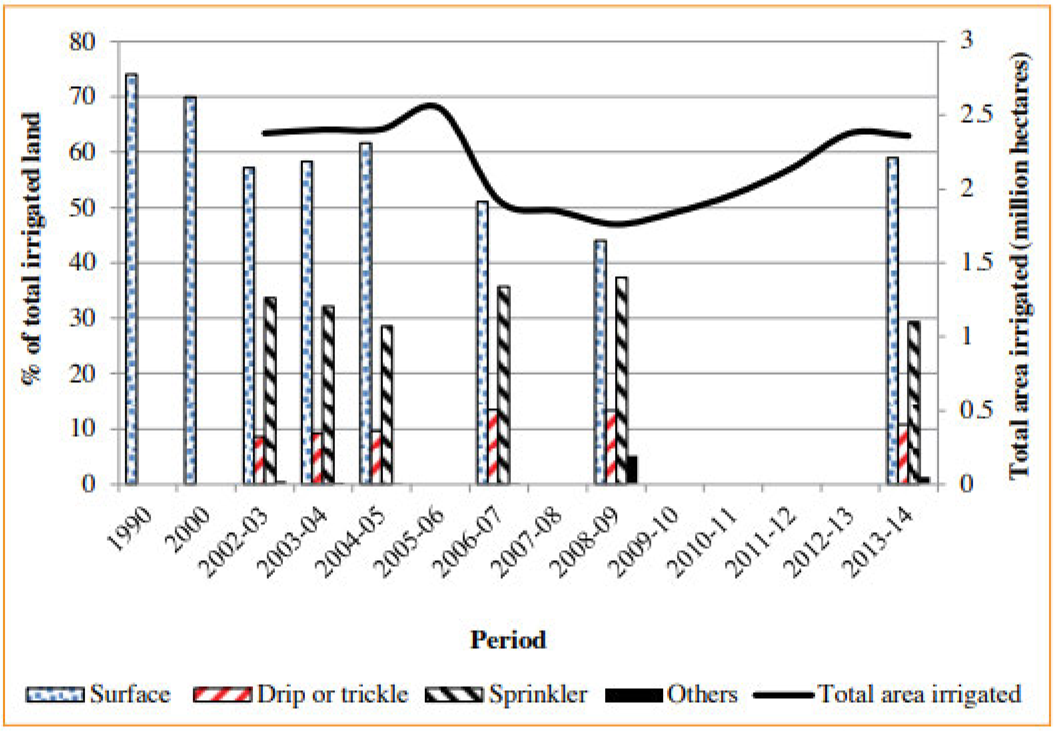

Figure 2.2 Proportion of Irrigated Land Area in Australia using different application methods from 1990 to 2014. (Koech, Smith & Gillies 2015).

The methodology of this research also included analysing new developments in the surface irrigation sector and how they can be used to increase the efficiency. It was established as per above that surface irrigation still contributes to the majority of irrigation events within Australia however farmers are choosing to adopt the more expensive yet more efficient lateral move and centre pivot sprinkler systems. As a result, the authors investigated aspects of system automation and hydraulic modelling to effectively produce feedback from the field and real time control over the event. The research yielded promising results with numerous systems being developed in the prior decades with intentions to significantly improve the performance of surface systems. Much of the complete autonomous designed system had only been conceptualised and therefore was not commercially available yet. Whilst the technology is still to be refined, researchers from a range of backgrounds have been able to model the movement of the water through the paddock in attempts to better understand how to maximise the crops water uptake.

The authors were able to collate the different simulation modelling in surface irrigation into table 2.1 below, paying specific attention to the benefits they offer. The different theories spanned from 1996 to 2015 all yielding a beneficial result in regard to water usage for surface systems. With reference to table 2.1, the most common strategies employed appear to be increasing the inflow rate and a reduced inflow time. In doing the theoretical modelling suggests that the water will flow towards the end of the furrow quicker and result in a more even water absorption across the entire paddock (Koech, Smith & Gillies, 2015). The practical application of these methods may yield some new problems however potentially in the aspect of erosion due to increased flow rate. The promising aspect however lies in the SIRMOD or SISCO simulation tools able to predict the irrigation event, with specific mention to the 2015 simulation of an automated border system using SISCO. Through the aspect of automation and hydraulic modelling Smith et al has demonstrated efficiencies of up 95% (2015). This is particularly promising data for Australian farmers looking forward to the future of surface irrigation. Whilst the data is of relative age, the Australian Bureau of Statistics are no longer collecting this information. It has however been well established that irrigation is still used more now than ever before and ultimately optimisation techniques will be required for the future sustainability of production.

Table 2.1 Benefits of Prior Simulation Modelling to Improve Surface Irrigation Systems (Koech, Smith & Gillies 2015).

Source	Location	Application system	Simulation tool	Strategy used	Benefits
Raine and Shannon, 1996	Burdekin River Delta	Furrow	SIRMOD	Decrease furrow length from 600 to 300m	Decrease of volume applied from 1.78 to 1.03 ML/ha/irrigation
Langat and Raine, 2006	Bura Irrigation Scheme, Kenya	Furrow	SIRMOD	Increased flow rate and optimised cut off time	Increased AE from 79.4 to 87.5%.
Raine *et al.*, 2005	Queensland, New South Wales	Furrow	SIRMOD	Optimised siphon flow rates and time to cut off	Water saving of 0.15 ML/ha/ irrigation
Smith et al., 2005	Southern Queensland	Furrow	SIRMOD	Increased flow rates, reduced inflow times	AE increased from average of 48% to 85-95%.
Smith *et al.*, 2009	Goulburn Murray Irrigation District (GMID)	Border	SIRMOD/ SISCO	Shorter irrigation times and higher flow rates	Gain in AE of 19%
Gillies *et al.*, 2010	GMID	Border	SIRMOD/ SISCO	Doubling flow rate (from 0.132 to 0.268 ML/day/m).	Water savings of 0.256 ML/ha/ irrigation (19% increase in AE).
Roth *et al.*, 2014	Australian Cotton Industry	Furrow	SISCO	Applying recommended flow and optimised cut-off	0.155 ML/ha per irrigation accounting for tail water recycling
Smith *et al.*, 2015b	GMID	Automated Border	SISCO		Efficiencies up to 95% demonstrated

Furthermore, the researchers compared the different types of irrigation systems with respect to water and energy usage. Table 2.2 depicted below demonstrates the level of input required for traditional surface, drip and centre-pivot irrigation systems, also with the addition of real time optimised surface irrigation. The aim of this study was to identify whether advancing surface irrigation can compete with pressurised systems in the future. It was found that centre pivot and drip irrigation boasted average efficiencies of above 90% with 4.4 and 4.2 ML/ha of water usage. They were however noted to have an elevated energy usage of 16,000 and 17,000 MJ/ha. This is a result of the technology required to pressurise the system. Current trends suggest that farmers are moving towards this technology with standard surface irrigation with a 55% efficiency comparatively using 7.3ML/ha of water with only 9,700MJ/ha in energy. Farmers are saving up to 3ML/ha with other systems despite the extra energy requirements. Koech, Smith and Gillies (2015) believe that farmers will find a surface system more appealing as a result of the lower input costs if the efficiency is similar to pressurised methods. Table 2.2 illustrates how a real time optimised surface system can produce 85% efficiency, using 4.7ML/ha in water whilst maintaining the same energy usage as standardised surface irrigation. Ultimately the research shows the future of surface irrigation can be optimised with modelling software to both reduce the water and energy usage.

Table 2.2 Comparison of Energy Usage for Furrow Irrigation Adaptations for a Hypothetical Crop (Koech, Smith & Gillies 2015).

System	Water applied (ML/ha)	Water savings (ML/ha)	Energy use (MJ/ha)	Increase in energy use (MJ/ha)
Current surface irrigation (AE 55%)	7.3		9700	
Real-time optimised surface irrigation (AE 85%)	4.7	2.6	9700	0
Centre-pivot irrigation (AE 90%)	4.4	2.9	17000	7300
Drip irrigation (AE 95%)	4.2	3.1	16000	6300

To conclude, the authors of this project have found that Australian agriculture is seeing a gradual 15% decline in the adoption of surface irrigation systems over the previous decades. They were also able to find research to support that new hydraulic modelling programs could effectively improve the efficiency of surface systems. This will attract more attention from farmers who are actively pursuing sustainable irrigation during unprecedented weather events. They finished by explaining that pressurised systems will continue to grow in Australia however surface irrigation will still be vital for future production.

2.2 SURFACE IRRIGATION

Surface irrigation in simplistic terms refers to the delivering of water to crops through a gravity-fed system where the water travels across the top of the ground (Taghvaeian, 2017). This has been employed for more than 6,000 years as one of the first engineering innovations for humans. Surface irrigation can generally be covered into four broad classifications including basin, border, furrow and uncontrolled flood irrigation. Research has revealed that furrow irrigation is most adopted form of surface irrigation implemented throughout Australian agriculture. As a result, the research to be conducted will focus on what is most applicable to Australian farmers. Furrow irrigation is the channelling of water in a singular direction utilising corrugations or 'furrows' that are specifically formed in the soil (FAO, 2024). This avoids flooding the entire field and causes the water to move down the furrows seeping into the walls and bottom to restore moisture in the soil (Taghvaeian, 2017). Traditionally these furrows receive an inflow from siphon tubes however there has been a more recent uptake of gated pipes.

As previously mentioned, surface irrigation systems including furrows have been recorded to have low efficiencies. In many cases 40 or more percent of water applied is escaping through deep percolation below the root zone and runoff at the tail drain. It has been reported that higher efficiency rates produce savings on labour costs and water usage, but further reduces the leaching of important salts, sediments and nutrients (Taghvaeian, 2017). A report analysed from Smith, Uddin and Gillies (2018) ultimately found that despite furrow irrigation being one of the most widely adopted methods globally it is still generally associated with low efficiency rates and high labour requirements**.** Taghvaeian (2017) reveals that there is a variety of factors contributing to the performance of irrigation, which this research project will aim to investigate in a furrow irrigation setting.

2.3 IRRIGATION PERFORMANCE

Irrigation performance is typically completed through a series of percentages that measure and evaluate an irrigation events ability to satisfy the previously set objectives, with the most important aspect being to fulfil plant water requirements. The first major term is the application efficiency, it is the most commonly referred to performance measuring measurements. Zerihun et al (1997) described it as a representation in a ratio or percentage of the volume of water stored in the intended region to the volume of water that escapes or is diverted. This is ultimately measuring the quantity of water that is in the root zone and available to the plant with a higher application efficiency desirable. A key part of the application efficiency calculation is understanding the root zone volume. This refers to how much water can be accessed by the plant across the entire field. The below equation is from a surface irrigation modelling system and demonstrates application efficiency:

$$Application\ Efficiency, AE = 100\% \times \frac{Vol_{RZ}}{Vol_{Inflow}}$$

$$Vol_{RZ}\ is\ Volume\ of\ Water\ that\ Infiltrated\ into\ the\ Root\ Zone$$

$$Vol_{Inflow}\ is\ Volume\ of\ Water\ applied\ to\ the\ Field\ or\ Furrow.$$

As can be seen understanding what the plant available water capacity is important for calculating an accurate application efficiency value. This value will be employed throughout the project to evaluate the percentage of water that is being utilised and how much is being lost in deep percolation and runoff. Similarly, the requirement efficiency can be calculated as a ratio of the water applied that infiltrates into the root zone compared to the overall volume that is required in the root zone area. It is calculated using the below equation:

$$Requirement\ Efficiency, RE = 100\% \times \frac{Vol_{RZ}}{Vol_{Req}}$$

$$Vol_{RZ}\ is\ Volume\ of\ Water\ that\ Infiltrated\ into\ the\ Root\ Zone$$

$$Vol_{Req}\ is\ Volume\ of\ Water\ required\ in\ the\ Plant\ Avaliable\ Water\ Capacity.$$

A final main measurement of irrigation is the distribution uniformity value commonly used to determine used to determine the consistency of infiltration throughout the entire field. Gillies and Smith (2015) calculate it as a ratio or percentage of the average depth in the lowest infiltrated quarter of the field/furrow to the average infiltration depth of the entire field/furrow. This is presented in the below equation:

$$Distribution\ Uniformity, DU = 100\% \times \frac{\overline{D_{LQ}}}{\bar{D}}$$

$$D_{LQ}\ is\ the\ Average\ Depth\ of\ Infiltration\ in\ the\ Lower\ Quartile$$

$$D\ is\ the\ Average\ Depth\ of\ Infiltration\ for\ Entire\ Field/Furrow$$

The distribution uniformity is a valuable measurement in assessing the performance of an irrigation event. Whilst there are many other factors these remain to evaluate the performance of an irrigation, they most summarised using the three above. Although the performance can be quantified it is also important to understand how these values can be changed or manipulated. Figure 2.3 below illustrates the effect of flow rate on application efficiency, requirement efficiency and distribution uniformity. The large flow rate in this particular example exhibits greater uniformity in terms of infiltration as the small inflow diagram starts with high infiltration and drops significantly at the end. The small inflow does not infiltrate into the entire root zone area as can be seen at the end of the row. This is different for the large flow which fulfils 100% of the root zone requirement. The last major aspect to note is that the large inflow whilst having better uniformity and requirement efficiency observes significantly more runoff than the small inflow rate. This is an exemplification of how this research project to be conducted may alter flow rates to achieve better irrigation performance.

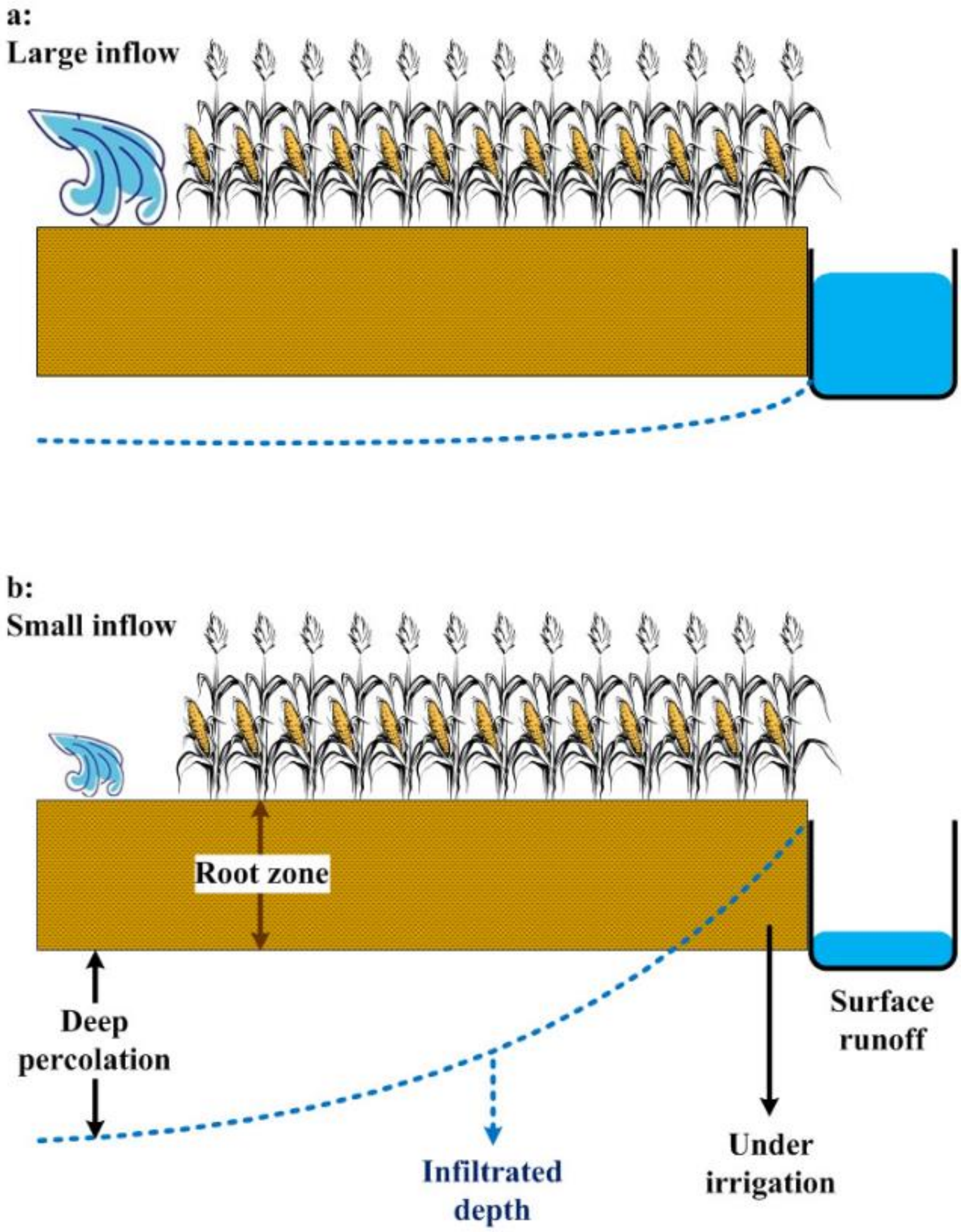

Figure 2.3 Diagram of the impacts of large inflow (a) and small inflow (b) on irrigation performance factors application efficiency, requirement efficiency and distribution uniformity (Taghvaeian, 2017).

2.4 IRRIGATION SIMULATION AND OPTIMISATION SOFTWARE

2.4.1 Review of Available Models

There are many software that have been developed and utilised throughout research to evaluate and model the performance of an irrigation event. They were originally developed to gain a better understanding of water movement in surface irrigation systems. This could allow the researchers to make recommendations to improve the overall application efficiency. A list of the most prominent modelling software's includes:

- SIRMOD
- WinSRFR
- IPARM
- SISCO

Research conducted found that each of the above modelling software have their own unique ability to model irrigation events, with some similar and different hydraulic principles/equations utilised for each one. They all appear to be potential suiters for this research project being conducted. Thomas Nyanda Reuben et al (2023) completed a comparison of the SIRMOD and WinSRFR models. The authors compared the modelling software across 3 furrows where the input data was kept the same. Ultimately Thomas Nyanda Reuben et al (2023) found that the SIRMOD model predicted 50.8% application efficiency to the WinSRFR of 51%. This illustrated that the models had a high degree of similarity for simulating the event in this particular instance. Whilst these could be utilised majority of the research conducted supports that SISCO is the most accurate and suitable option for research usage. One of the first aspects is the more user friendly user interface that makes it more simply to operate. The research also suggests that it has sufficient accuracy to complete this task. Furthermore, it features a multiple furrow and optimisation feature that is not addressed in other modelling programs. This aspect allows for adjusting flow rate and irrigation cut off times to maximise the application efficiency. It is an important aspect for the analysis of field variability as it can compute the different furrows in a singular function and thus is most appropriate for this research.

2.4.2 SISCO

SISCO is an acronym for Surface Irrigation Simulation, Calibration and Optimisation. It is a hydraulic model that utilises the open channel flow one dimensional Saint-Venant equations to simulate the process of surface irrigation (Gillies and Smith, 2015). This program is aimed at providing farmers and researchers with software that can provide better understanding about the movement of water throughout the irrigation event. To effectively simulate this, SISCO must accommodate for temporal variations which may include inflow rates, surface roughness, slope, furrow geometry and soil infiltration. As described throughout, the objective of this project is to consider spatial variability in furrow irrigation which is not discussed in the paper by Gillies and Smith (2015).

The calibration component of SISCO refers to its ability to yield results that are similar to real world surface irrigation data. It is important to note that this system is only applied to surface irrigation. Gillies and Smith establish the principle that hydraulic modelling could allow the efficiency rate of surface irrigation systems to improve dramatically. Previously, complex models such as WinSRFR (Bautista et al, 2009) and SIRMOD (Walker, 2005) have been utilised to model the flow of water and predict soil uptake of water.

Gillies and Smith (2015) provide a detailed layout of the mathematical procedures and methods to develop the program. Quite simply they found that the principles of conservation of mass and conservation of momentum can be used to describe the flow of surface water across an irrigation field (Gillies and Smith, 2015). With the assistance from a pre-existing simulation engine, Gillies and Smith were able to develop a series of hydrodynamic equations to describe the movement of water down the field. The SISCO system allows the user to interact with many particular variables that are specific to the area of which the irrigation event is taking place. This is exemplified in figure 2.4b where an operator is able to input the certain parameters. The next step is simply for the SISCO software to generate both graphical and tabulated results. This is demonstrated in figure 2.4c of which an infiltration graph can be viewed. The different results ultimately inform the researcher or farmer where the water is spreading to with a rather accurate prediction of infiltration depth in relation to distance and time. The SISCO software is also able to play an animation that plays an accelerated version of the fields irrigation event under analysis. Gillies and Smith (2015) have made SISCO adaptable configuring it in a way that accounts for some of spatial variability across the length of the furrow/bay.

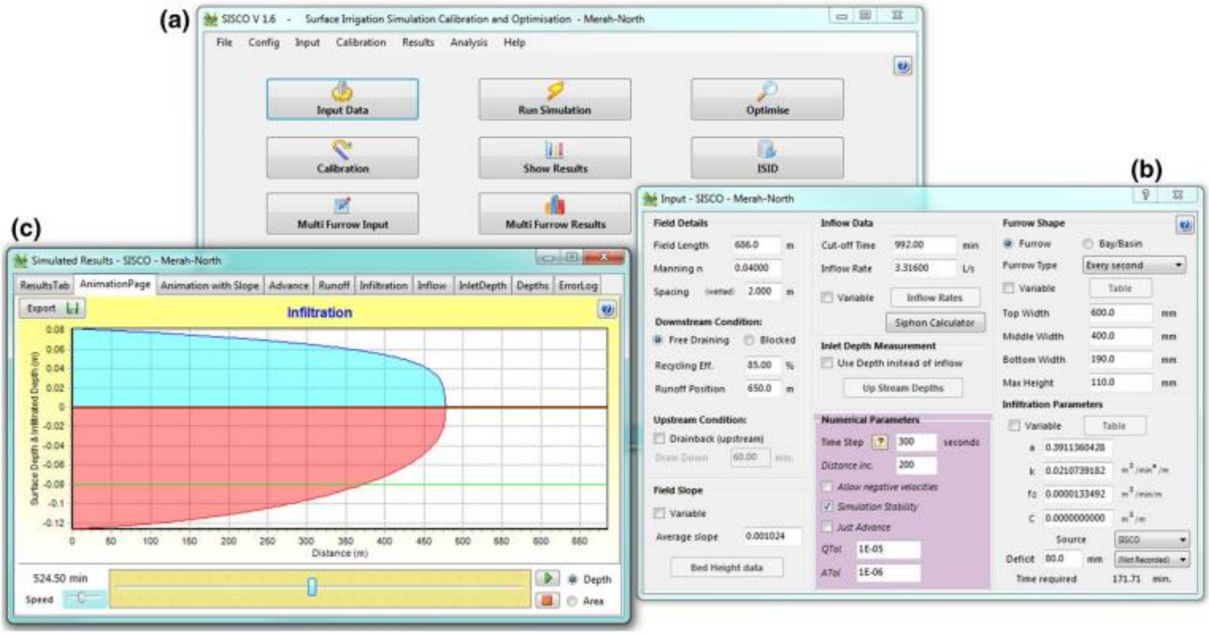

Figure 2.4 Example of the SISCO Main (a), Input (b) and Animated Results (c) Windows (Gillies and Smith, 2015).

To complete the SISCO program the authors had to validate the simulation engine is able to accurately model an irrigation event. Given the numerous parameters that vary from location to location, it was important that the methodology included a series of calibration case studies. The last of the calibration studies completed by Gillies and Smith is depicted below in figure 2.5 and table 2.3. This process involved comparing the hydraulic modelling of both SISCO and IPARM to a measured bay irrigation event. IPARM is a model that utilises a volume balancing technique that estimates the surface storage upstream and thus takes the manning's number (*n*) at this particular point. The report states that the comparison between SISCO and IPARM throughout the calibration stage was to illustrate the potential differences/benefits (Gillies and Smith, 2015).

It is demonstrated in figure 2.5 that the SISCO program can effectively track the flow of water through a given field providing predictions that are close to that of the measured data. The authors extrapolated additional information to tabulate some of the crucial differences. This is exemplified in Table 2.3, which has numerical data illustrating the difference from measured data to the SISCO and IPARM modelling. The key take aways lie within the application efficiency (Ea), requirement efficiency (Er), low quarter distribution uniformity (DU) and run-off. Across all aspects the SISCO hydraulic modelling software yields more accurate results, specifically with the DU which is 94.9% for SISCO and only 53.4% for IPARM. Gillies and Smith also mention the aspect that IPARM used constant parameter value which ultimately resulted in 0mm of runoff projected to have reached the end of the bay. This is drastically different to the 13.2mm that was measured and a rather accurate 14.6mm predicted by SISCO. Ultimately Gilles and Smith (2015) were able to develop and conclude that SISCO is able to identify infiltration and Manning's *n* more effectively than other traditional models currently used.

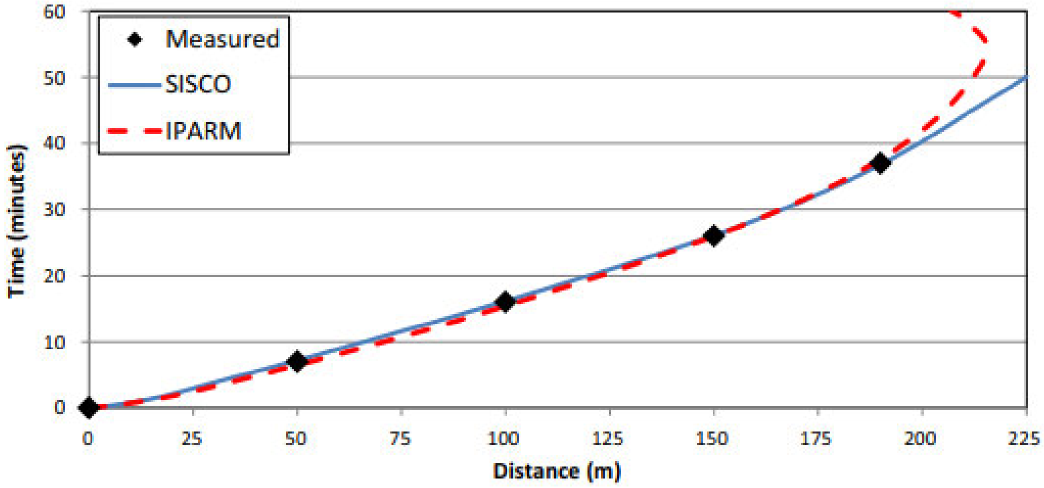

Figure 2.5 Calibration Case Study 3 Graph of Measured, SISCO and IPARM data for 'Bay 2' (Gillies and Smith, 2015).

Table 2.3 Calibration Case Study 3 Tabulated Results for 'Bay 2' (Gillies and Smith, 2015).

	Ea (%)	Er (%)	DU (%)	Run-off (mm)	D_p (mm)	D_{ave} (mm)	D_{max} (mm)	D_{min} (mm)
Measured[a]	78.2	97.2	–	13.2	0	47.1	–	–
SISCO	75.6	94.0	94.9	14.6	0	45.6	47.7	40.4
IPARM	73.3	91.1	53.4	0	16.1	60.3	75.7	0

[a] Measured performance is based on measured data and the assumption of zero drainage

The last crucially relevant factor found from this research conducted is SISCO's commercial potential for Australian farmers who operate surface irrigation systems. As depicted above in table 2.3 the efficiency of the operation is just below 80%. This is extremely promising for the future given that SISCO with future research can allow for producers to understand the irrigation requirements to ultimately achieve higher efficiency rates consistently. It is also important that SISCO exhibits high accuracy for the usage in this field variability surface irrigation research.

2.5 OPTIMISING IRRIGATION PERFORMANCE

2.5.1 Techniques to Optimise Irrigation Performance

It is the goal of farmers to optimise and improve their entire farming operation. Within an irrigation setting, optimisation refers to the enhancing water efficiency, promoting crop health and contributing sustainable farming practices (CROPNUTS, 2024). Surface irrigation can be extremely difficult to consistently be efficient particularly when compared to pressurised systems such as centre pivots. As mentioned, there are many irrigation modelling software's that can assist in simulating events to then enhance. Much of the enhancement comes from changes to ground slope, flowrate and duration of the irrigation event (Taghvaeian, 2017). SISCO modelling software has the capacity to perform an optimisation simulation which allows the user to find the ideal irrigation event. This optimisation feature on SISCO will be an imperative to collaging the results of multiple furrows simultaneously to provide recommendations on irrigating with field variability.

2.5.2 Optimisation using SISCO

A research paper was published in 2016 by Smith et al with the main purpose to evaluate the performance of automated bay irrigation systems. The specific objective was to demonstrate the application efficiency rate that is achievable for automated high flow bay irrigation in the Northern Victoria area (Smith et al., 2016). The authors found that the application efficiencies for furrow irrigation events would only average 50% but could vary from as low as 10% all the way to 90%. Prior literature in the area was noted to have failed in addressing if automation in this particular area can yield the consistently improved application efficiencies that were based purely on the duration of the irrigating. It has been observed before in the cotton industry that the increasing of furrow inflow rates to 6L/s combined with a reduce time to cut-off can potentially increase the average efficiency to 75% (Smith et al 2005). This data was a promising ground for Smith et al (2016) to investigate whether this process can be automated and used to reduce the water usage in surface irrigation.

The methodology of the project conducted by Smith et al (2016) included utilising the SISCO hydraulic modelling software to project the optimal duration of the irrigation event. The study was conducted across a series of nine farms in the Goulburn-Murray Irrigation District (GMID) of northern Victoria. The specific farms selected had already invested in the Rubicon FarmConnect^{TM} on farm automated irrigation infrastructure. It was mentioned throughout the report that a range of trial locations would provide a better range of results and mimic the real world spatial variability that is observed in agriculture. The study farms at this period had a variety of crops which included permanent pasture, soybeans, maize and lucerne. More importantly the soil composition varied greatly across the trial locations. Finally, the research required Rubicon FloodTech depth sensors and SmartMeter Gateway to monitor the behaviour and movement of the water throughout the trial. As depicted below in figure 2.6 SISCO was setup for each farm and utilised with the intent to model the expected irrigation event to effectively automate the shut-up procedure. The SISCO software as alluded to earlier is excellent for running a calibration that can find the most appropriate infiltration parameters. Figure 2.6 shows a relatively accurate calibration in comparison to the dots of which are measured depth values.

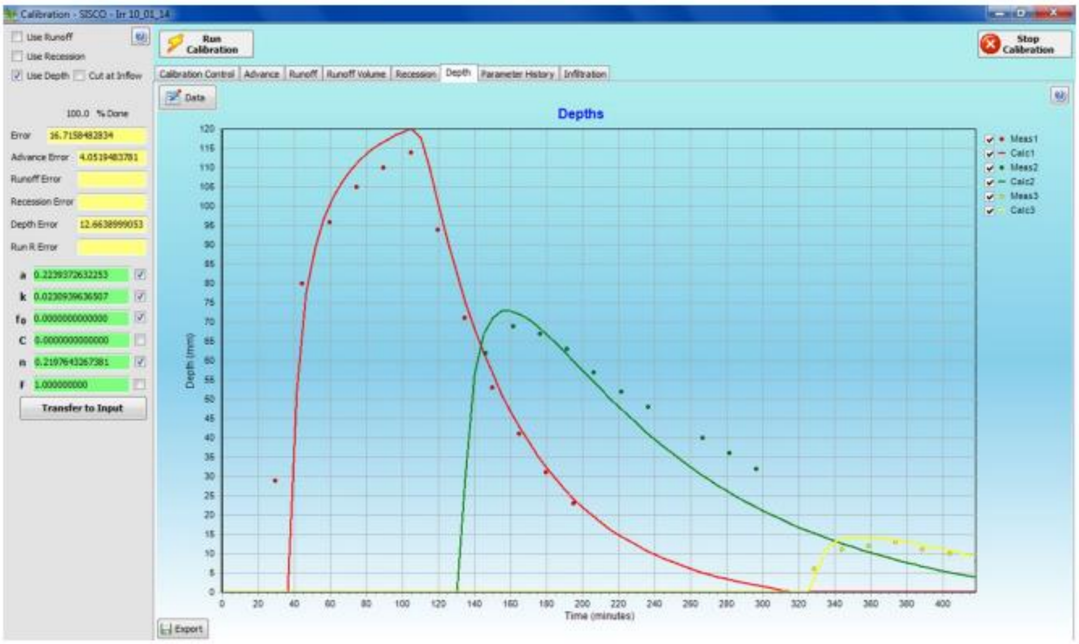

Figure 2.6 Calibration Screen of SISCO demonstrating the fitting of the waters measured depth (dots) vs simulated depths (line) along an irrigation bay (Smith et al., 2016).

The results from Smith et al (2016), yielded in excess of 90% for application efficiencies for surface irrigation which is comparable with pressurised irrigation methods such as lateral move sprinklers and drip irrigation. This provided the foundations to conclude that it is certainly achievable to increase the efficiency of surface irrigation through precise automated management. Table 2.4 below provides a brief summary of the application efficiency results from each trial site with a recommendation for future actions. As depicted the range of application efficiency spans from a low of 56% to a high of 95%. Despite the lack of overall consistent results, the main takeaway was the ability to increase the overall efficiency of surface irrigation practices. Smith et al (2016) goes on to explain that certain unavoidable weather events, management practices and trial quantities from specific locations may have affected the data accuracy. Overall, the research results illustrated potential for automated bay irrigation to have increased application efficiency.

Table 2.4 Summary of Application Efficiency Results from Each Trial Farm (Smith et al., 2016).

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

Smith et al. (2016) chose to investigate the individual results from Farm A specifically, with the belief that it showed some of the best potential for the automated process. Table 2.5 below reveals the detailed data from each of the 6 individual irrigation events. A major aspect of the results was the ability to yield an application efficiency (E_a) percentage in the 90th percentile. This level of efficiency can be directly compared to the usage of other pressurised sprinkler and drip irrigation systems, without the excessive input costs. This particular farm yielded more consistent results in comparison to other trials due to the grower displaying improved and consistent management practices regarding the irrigation of this field. It was reported that the farmer would employ the automated bay irrigation at the same moisture content level for each event. This allowed SISCO to provide a more accurate and optimised cut off time. Furthermore table 5 also outlines a lower run-off percentage which is a great aspect for reducing the usage agricultural water.

Table 2.5 Individual Results from Each Event at Farm A (Smith et al., 2016).

Date	E_a (%)	Deficit (mm)	E_r (%)	Run-off (%)	Deep drainage (%)	Ave depth applied[b] (mm)
26 November 2013	92	80	99	2.8	5.1	80
23 December 2013	90	80	88	9.6	0.0	71
10 January 2014	96	80	99	0.6	3.5	79
3 February 2014	98	80	93	0.0[a]	2.3	75
1 March 2014	98	80	91	1.3	0.5	73
22 March 2014	96	80	78	4.5	0.0	63

[a] Advance did not reach end of field

[b] Average depth applied is the depth of water added to the root zone store averaged over the length of the bay

To conclude, Smith et al (2016) have thoroughly researched and reported on the performance of automated bay irrigation systems. The vast range of numerical data across many varying trial locations have provided great insight into the factors and technologies that can affect the efficiency of irrigation. From this information the authors were able to deduce improved methods for selecting the duration of an irrigation event. They were able to conclude that changes to soil infiltration characteristics, pasture height and density and variations in flow rates can be the determining factor to the effectiveness of the automated bay irrigation. When optimised the results proved that the system has potential to raise efficiency close to and even above 90%. This overall is a large step towards improving the sustainability of future surface irrigation systems against new pressurised setups. SISCO will be extremely useful in the modelling of the irrigation event but furthermore allow for providing optimised recommendations for future irrigating.

2.6 FIELD VARIABILITY FACTORS INFLUENCING IRRIGATION PERFORMANCE

The performance of surface irrigation is influenced by a range of factors many of which are related to soil characteristics. Research has investigated how varying soils types affect the performance of irrigation systems. The infiltration rate, one of the key drivers of performance is determined by the physical and chemical soil properties. There are many contributing factors to the soil of which include texture, pH and structure. Furthermore, variability is often impacted by nutrient and soil organic carbon levels however this project is focussed particularly on machinery induced compaction. These key attributes affect the soils moisture retention ability which is of utmost important for irrigation.

Many of these characteristics vary dependant across geographical location, however the idea of spatial variability denotes that these differences are found across a singular agricultural paddock also. These slight variations in the soil can have huge potential impacts on compaction level, nutrient uptake and the infiltration rate. Understanding the variation of the infiltration is crucial in attempting to measure the variability of surface irrigation systems, making it ever valuable to inspect for soil changes at the chosen test locations.

The soil type and composition has a prominent influence on the water holding capacity and infiltration rates. Prior experience in this area has revealed the influence of clay content on the ability to retain moisture. Research supports that smaller particle soils (predominantly silt and clay) have a higher water holding capacity when compared to sandy soils (Ball, 2022). Sandy soils tend to have lower water holding capacity but are renowned for faster and higher infiltration rates. This is a general rule however the exact values for the testing to occur should be considered given how significantly soil characteristics can vary from point to point. The importance of soil characteristics will influence the methodology and particularly the locations for the testing to follow.

A recent study by Smith and Uddin (2020) focused on the selection of flow rate and time to cut-off in a high performance bay irrigation setting. Prior performance evaluations in this area of research found higher flow rates than recommended can lead to an increase of up to 20% application efficiency in bay irrigation. This high flow rate as discussed above also requires consistent management and a reduction in the duration to achieve the efficiency advantages. The main objectives of this study were to determine the optimal flow rates for representative cracking and non-cracking soils of the southern Australia region, and also to evaluate the requirements to implement real time to cut-off estimation technology (Smith and Uddin, 2020). The authors aimed to collect data and to produce results that can provide guidance to farmers who wish to achieve better performance for their irrigation.

As mentioned, the study was conducted in the southern Murray Darling Basin of northern Victoria and southern New South Wales (Smith and Uddin, 2020). Specific to this area the authors have identified a total of 4 cracking soils and 3 non-cracking soils to analyse for irrigation purposes. The identified cracking clay soils are detailed in the report and separated predominantly by the infiltration rate and moisture deficiency for each sample. The 3 non-cracking soils show more variation and are separated primarily by their low, medium and high permeability. This will allow for better understanding of how the infiltration characteristics as a result of varying soil types can affect the performance of surface irrigation systems. In order to visually understand the results, Smith and Uddin have utilised the SISCO hydraulic simulation model software (Gillies and Smith, 2015) to compare the results for each of the length, flow rate and duration combinations.

Depicted in figure 2.7 and 2.8 is the graphical representation of relationships between cumulative infiltration, soil type and duration of irrigation event. For this particular case study, the flow rate remained the same across the board with the intent to specifically identify the effect of soil and its infiltration characteristics. As demonstrated in figure 2.7 the cracking soils generally comprising of some clay content, has an extreme burst of infiltration of between 20mm to 40mm within just minutes. This is then followed by a major drop in gradient and a steady somewhat plateau over the remaining 400 minutes. This is a vastly different result compared to figure 2.8 of the non-cracking soils which display a gradual curve of infiltration over the time period. It begins with a quick uptake of around 10mm in the first 10 minutes however it continues to grow steadily with a gradual gradient decline. It does not appear to plateau as readily as the cracking soil of figure 6. In regard to the specific non-cracking soil types, it is clear the higher permeability soil (N3) experiences the most infiltration out of all soils tested. The relationship is clearly visible with soil permeability affecting the amount of water infiltration over time. Overall, it would appear that the cracking soils would be more likely to reach their saturation point first and will tend to hold the water in the root zone longer.

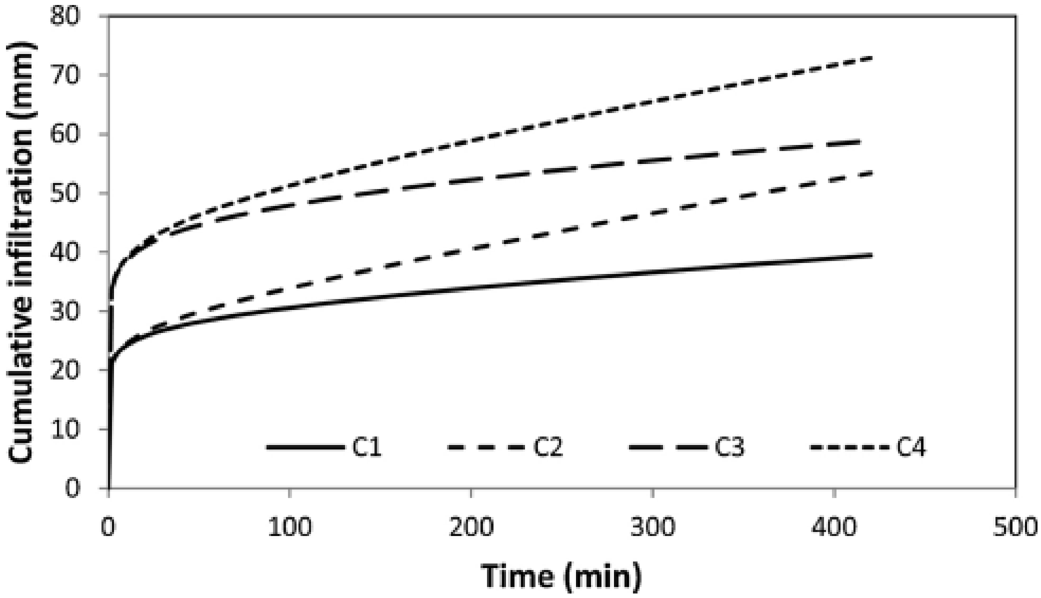

Figure 2.7 Representation of the Infiltration Characteristics for Different Cracking Clay Soils (Smith and Uddin, 2020).

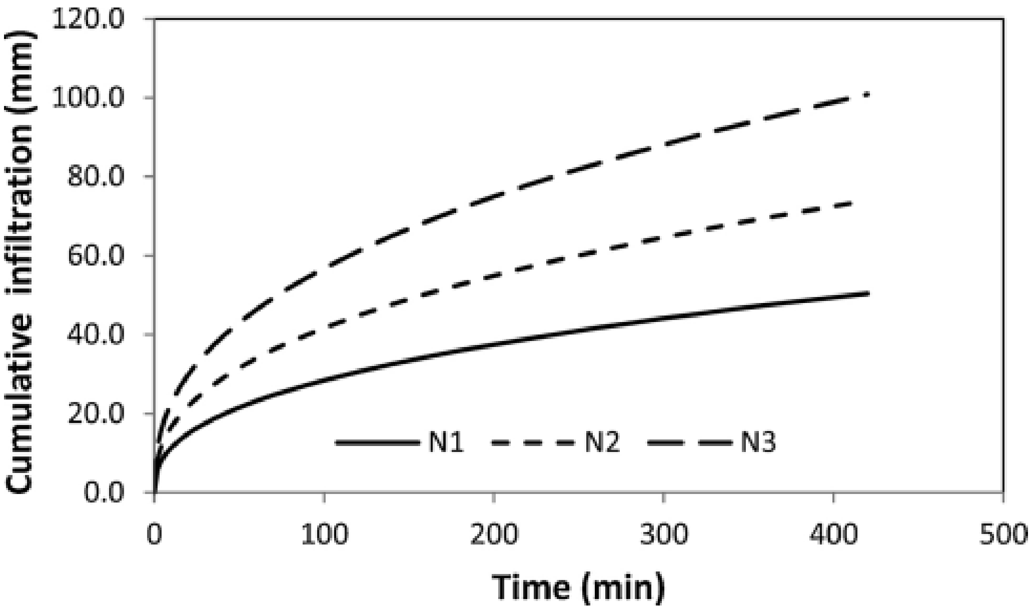

Figure 2.8 Representation of the Infiltration Characteristics for Different Non-Cracking Soils (Smith and Uddin, 2020).

Smith and Uddin (2020) worked towards simulating the effect that varying the flow rate would have on the application efficiency (Ea), requirement efficiency (Er), optimum time to cut-off (Tco) and distance reached by irrigation advance for the 400 meter long bay (Xco). The results of these were graphed in figure 2.9 for the first cracking soil type (C1) and in figure 2.10 for highest permeability non-cracking soil (N3). Excluding the soil type all parameters including slope, length and Manning's number were kept constant for comparative purposes. The first note from both soils in figure 2.9 and 2.10 is that the optimal time to cut-off (Tco) would experience a large drop off around 1.7 L/s/m for cracking soil and 2.5 L/s/m for the non-cracking soil. The results for cracking soil show the duration would drop in a theoretical sense from 400 minutes to just 70 minutes at approximately 4.6 L/s/m. In the case of non-cracking soil similar duration times were found however finishing with higher inflow rate of about 7.8 L/s/m. It was seen that the cracking soil boasts higher application efficiency ratings with a plateau around 92% whereas the permeable soil appeared to level at ~88%. The best application efficiency for the N3 soil was towards the higher end of flow rate however the C1 soil had achieved optimum efficiency around 1.8 L/s/m and did not vary from this value. The requirement efficiency for both studies revealed to be close to the targeted 100% with a very steady decline noticed as the flow rate increased. This ultimately meant that the water would infiltrate the 40 mm of moisture deficient soil. Lastly the distance of the advance at the time of cut-off was found to have declined rapidly from 240m at ~1L/s/m to 120m at ~4.6L/s/m in the cracking soil case. This would suggest that the water still had not covered the remaining 50% of the bay irrigation. The results for the non-cracking clay were slightly varied with it progressing an extra 80 meters at the cracking soils corresponding flow rate. This data was used further throughout the Smith and Uddin's (2020) report in attempting to select the optimum flow rate for application efficiency. This is valuable information as it proves that soil characteristic affect the optimal irrigation flow rate and duration. This report will aim to effectively evaluate the different compaction levels throughout the field to recommend an optimised strategy.

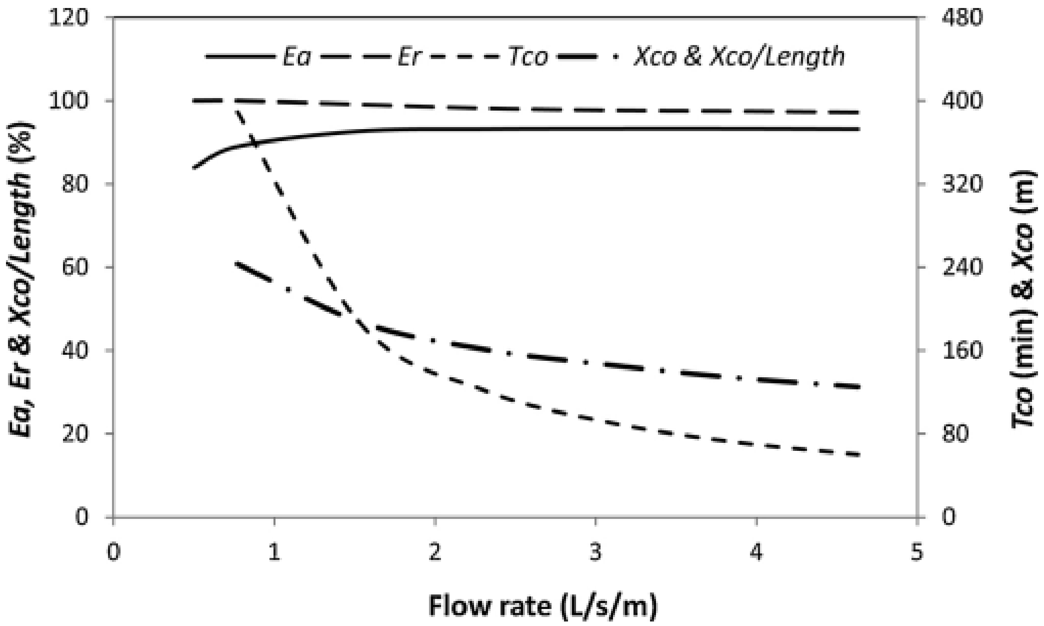

Figure 2.9 Example results of the Summer Pasture Trial, of a 400m Cracking Soil (C1) Bay with Slope of 1:750 and 40mm Moisture Deficiency (n=0.26) (Smith and Uddin, 2020).

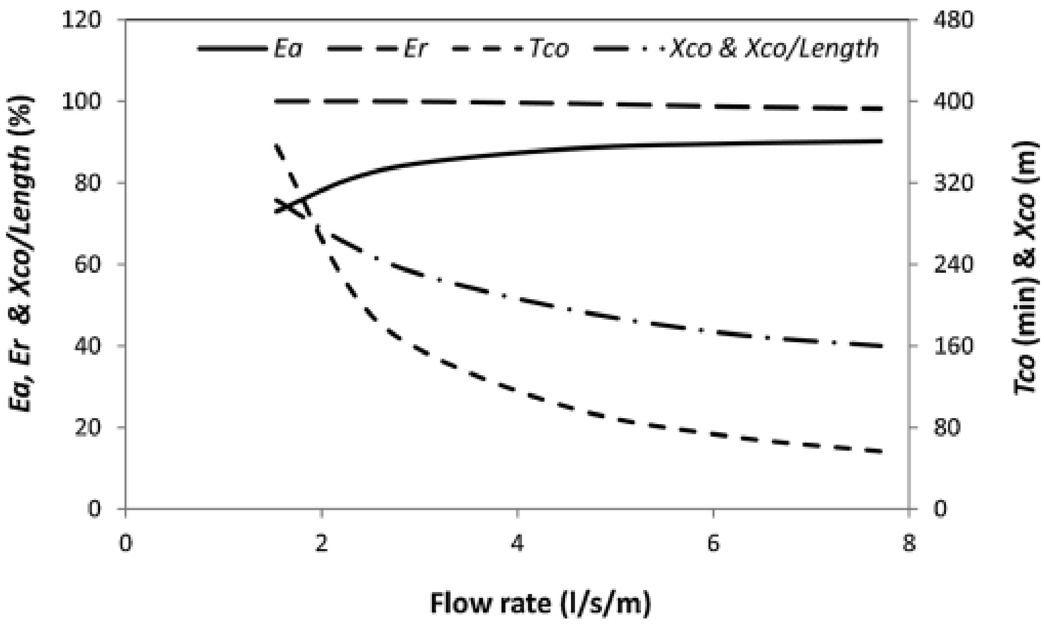

Figure 2.10 Example results of the Summer Pasture Trial, of a 400m Permeable Non-Cracking Soil (N3) Bay with Slope of 1:750 and 60mm Moisture Deficiency (n=0.26) (Smith and Uddin, 2020).

Smith and Uddin (2020) created a schematic in figure 2.11 depicting the water movement for a high flow rate, short time to cut-off irrigation event. This particular event was designed to maximise the application efficiency. They forecast the duration of the water to be applied for just 120 minutes, whilst infiltration shall occur for at least 270 minutes before run-off can occur. The researchers developed this model to allow for 5% total run-off as a safety factor. They expect the water runoff to have concluded at approximately 7 hours into the irrigation event. Figure 2.11 also shows that deep drainage is still expected to occur for approximately 7% of the water applied starting around the 90 minute mark. Whilst the model still has water lost through run-off and deep drainage, it is still a significantly improved application efficiency to current practices. To test this theory, they tabulated application efficiency data to do a direct comparison.

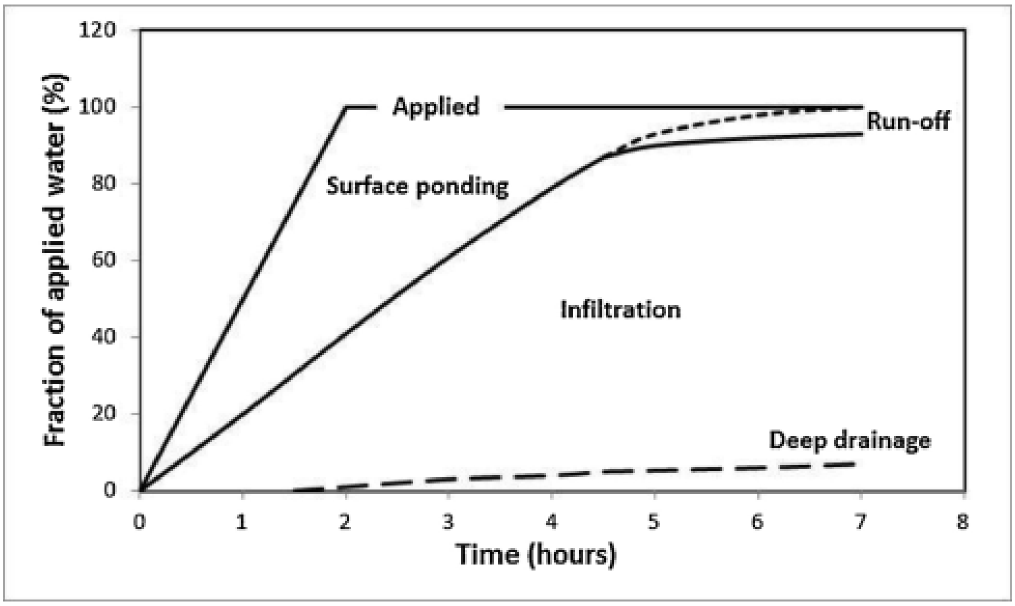

Figure 2.11 Schematic of the Water Movement for an Efficient Bay Irrigation Event with High Flow Rate and Short Time to Cut-Off (Smith and Uddin, 2020).

Similar to a previous study conducted by Smith, Uddin and Gillies in 2018, they chose to compare different irrigation time to cut-off based upon different strategies. Outlined in table 2.6 it can be seen that they have analysed the duration for farmer, optimum and managed which is a derived equation from the prior data collected. The farmer strategies as demonstrated is approximately 110 minutes for each irrigation event even despite differences in the moisture content of the soil. As a result, this method employing farmer experience yields application efficiency values between 48% to 77%. The optimum method is much more efficient with the time to cut off varying dependant on the moisture deficiency. The use of a modelling software like SISCO consistently yielded 95% in terms of efficiency. The last method presented in this report utilised a customised linear equation to predict the best time to cut-off. This method yielded promising results with a range from 76.4% to 95%. Although it is relatively accurate the equation is only relevant for those particular field dimensions and soil composition of which the trials were conducted. It is significantly better than the farmers traditionally approach but also is not as intensive as the hydraulic modelling programs.

Table 2.6 Comparison of Farmer, Optimum and Real-Time Managed (using linear equation) Irrigation Performance (Smith and Uddin, 2020).

			Farmer		Optimum		Managed (equation 5)		
Date	Deficit (mm)	*n*	*Tco* (min)	*Ea* %	*Tco* (min)	*Ea* %	*Tco* (min)	*Ea* %	Runoff %
29 Jan 14	29	0.060	110	55	43.0	95	43.0	95.0	5.0
4 Feb 14	45	0.060	110	70	67.6	95	67.4	95.0	5.0
11 Feb 14	57	0.070	110	77	82.1	95	92.0	87.4	12.6
23 Feb 14	31	0.083	115	48	33.5	95	48.7	76.4	23.6
8 Mar 14	43	0.090	110	67	64.0	95	73.2	87.7	12.3

The overall report provides a detailed understanding of the influence of soil type in irrigation systems and particularly how understanding them can assist in the selection of the time to cut-off. The authors recognise the accuracy of a hydraulic modelling system however have created a simple equation to determine cut off times without the need for extra skills and labour. Whilst this particular equation may only be relevant for the specific soil types in this particular area tested, it still provides solid grounding for more research to be conducted around improving the management of surface irrigation systems.

2.7 METHODS TO ACCOMMODATE FOR FIELD VARIABILITY

A crucial aspect to improving the performance of surface irrigation systems is identifying the optimal irrigation duration for that specific location. Thus Smith, Uddin and Gillies (2018) have completed research on the estimating the duration of a high performing furrow irrigation. This study is specific to cracking clay soil types and therefore does not account for any field variability that is commonly encountered in Australian agriculture. Prior research in this area have found that further increases to irrigation efficiency can only be brought about by management of individual irrigation events. This more specifically is referring to the farmers management practices and the varying of flow rate and the time to cut-off (T_{CO}). As discussed previously there have been many new methods for estimating the optimal irrigation time, with most new research into hydrodynamic simulation modelling. The most prominent predicting systems included SIRMOD (Walker, 2003), WinSRFR (Bautista et al., 2009) and SISCO (Gillies and Smith, 2015) or specific design charts (Smith, Uddin and Gillies, 2018). Smith, Uddin and Gillies (2018) believe that this modelling technology is data intensive and complex in operation which can ultimately discourage farmers from investigating further.

The methodology for Smith, Uddin and Gillies (2018) research involved the comparison of different methods for estimating the time to cut-off using a series of field trial data. The first method to be investigated was the farmers projected irrigation duration which is highly unpredictable and a traditional method which can rely heavily on farmer experience. The second method was the mean of the individual optimum irrigation duration. This was achieved by determining the optimal time to cut-off for the designed flow rate with a runoff volume of 5% of the inflow using software assistance. The reason for the target runoff was to provide a small margin of safety to ensure that the advance would reach the end of the furrow (Smith, Uddin and Gillies, 2018). The third method was cutting off the water when the advance reaches a certain distance along the furrow. Smith, Uddin and Gillies (2018) also investigated some mathematical derived values based around achieving 5% runoff, requirement efficiency of greater than 90% and relationship of time to achieve 50% advance (labelled as Eq.2). These particular theoretical time of cutoff were purely experimental and used to gauge whether there is a simple relationship to assist producers with irrigation. The researchers decided to model the irrigation events for each of the different methods using SISCO. This would ultimately allow the authors to evaluate which method can provide the highest performance for this particular soil type.

Below in table 2.7 the time to cut-off can be found for the farmer, individual optimum and set distance trials. The first takeaway is the actual performance achieved under the farmers management and general perception is comparatively higher in duration, with relatively low efficiency and high variations. This is evident in table 2.8 which illustrates the application efficiencies of each method. The farmer method yielded results ranging from 49% to 90%. The main outlier throughout table 2.7 is the real time approach which had extreme variations in duration of irrigation resulting in poor efficiency as low as 26%. Using the relationship of 50% advance of equation 2 and 5% runoff were relatively efficient with a variation generally between low 60% and the high 90th percentile. It some particular cases they yielded some of the best results however as per the table no one method outperformed the rest across the board. The set distance method was found to be consistently better than most of the other methods however it did also display variation across each irrigation event. On some occasions it yielded less time to cut-off than the individual optimum and in other circumstances it was more. Generally, the application efficiency of set distance varied from 64% up to 95%, which ultimately is an improvement but lacks consistency. Lastly the individual optimum one also yielded better results than traditional farmer predictions however it was still on many occasions behind or even with the set distance.

Table 2.7 Time to Cut-Off in Minutes for Field (T17) for Various Estimation Methods (Smith, Uddin and Gillies, 2018).

Irrigation	Farmer	Individual Optimum[a]	Set distance	Eq. (2)	Real-time (Er > 90)	Real time (5% runoff)
2	740	591	516	495	434	555
4	837	624	604	616	614	505
3	650	361	370	386	398	400
5	380	326	272	286	1586	150
7	463	414	460	483	560	420

[a] Mean of the individual optimum *Tco* values for the four furrows.

Table 2.8 Irrigation Application Efficiency (%) for the field (T17) using the Various Time to Cut-Off Estimation Methods (Smith, Uddin and Gillies, 2018).

Irrigation	Farmer	Individual Optimum	Set distance	Eq. (2)	Real-time (Er > 90%)	Real time (5% runoff)
2	49.5	58.6	64.2	65.2	66.8	61.5
4	54.5	70.9	73.2	74.1	72.2	77.6
3	70.6	95.0	95.1	86.4	90.0	89.7
5	90.3	95.0	95.0	96.9	26.1	98.8
7	81.8	95.0	86.8	83.8	74.9	92.5
Mean	69.4	82.9	82.9	81.3	66.0	84.0

Further investigation conducted in table 2.9 mostly supported the trends set in the prior testing. They looked specifically at the farmer, optimum, set distance and time to cut-off relationship with intent to understand how the water penetrates the soil to the entire root zone (or requirement efficiency, Er). Whilst the farmers method was extremely wasteful with water usage, it did allow for water to reach on occasions 100% of the required root zone. Optimum method was once again a better alternative, yielding some of the better application and requirement efficiencies compared to the alternative methods. The final two methods in table 2.9 were also promising in terms of application efficiencies, however the author noticed that at least once for each method the water did not advance to the end of the field. In a practical sense this means that the crop planted at the end of the furrow is not receiving any water from the irrigation event. Whilst the theoretical application efficiency is similar to the optimum it does however leave a weak spot in terms of crop productivity.

Table 2.9 Irrigation Application and Requirement Efficiencies (%) for Individual Furrows of a Cracking Clay Soil (Smith, Uddin and Gillies, 2018).

Furrow	Farmer		Optimum		Set distance		T_{co}/T_{50} (Eq. (2))	
	Ea	Er	Ea	Er	Ea	Er	Ea	Er
#12	52.1	94.3	92.2	88.4	79.3	89.9	71.7	90.9
#41	27.9	100	94.8	92.4	95.3	92.3	96.9	91.9
#61	63.6	100	75.4	100	82.8[a]	98.6	74.0	100
#74	87.8	100	87.8	100	93.7[a]	98.2	79.6	100
#87	25.7	100	83.4	99.9	72.7	100	71.6	100
#91	75.9	99.9	93.2	97.7	69.9	100	86.0	99.1
Ba	85.8[a]	90.8	79.9	99.8	87.1[a]	86.7	77.7	99.9
By	56.7	100	93.4	94.6	94.0	93.4	99.5	91.4
F	86.5	99.2	89.8	93.7	87.5	98.9	85.9	98.6
K	66.3	99.6	92.8	62.7	94.6	61.3	99.8[a]	56.4

[a] Advance did not reach end of field.

To conclude the report from Smith, Uddin and Gillies was aimed at estimating the duration time for a high performance furrow irrigation on cracking clay soils. This report was successful in identifying a range of methods varying in overall complexity that would effectively increase the irrigation efficiency. They found current practices implemented by experienced farmers are not the best method particularly in areas of cracking clay vertosol soils. The investigation into irrigation durations revealed a simple linear relationship between the time to cut-off and time for the advance to reach the halfway point along the furrow. A mathematical relationship was created specific for these field trials with the results from testing showing great potential. Whilst utilising hydraulic modelling software remains one of the most effective methods to increase surface irrigation efficiency, the authors identified the problem with the complex system being adopted. To counteract this, they were able to devise simple numerical relationships that were successful to guide farmers in their future irrigation practices.

2.8 SENSOR TECHNOLOGY FOR COLLECTING ADVANCE DATA

Through the literature that has been reviewed one of the main aspects required for the calibration of soil infiltration characteristics is to effectively track the advance wave movement. There are many different designs that have been utilised by researchers for research purposes only. It appears that there is a large gap surrounding the integration of these sensors for on farm usage all year round. Some of the available advance and end of row moisture sensors have been developed by Commercial Business Radio (CBR) in Utah, USA and by Prescott Farm Innovations in Idaho, USA. The Utah State University (2021) completed an analysis and comparison of the two advance sensors projecting the potential benefits from each of the sensors. The Wet Stake solar-powered irrigation advance sensor from Prescott Farm Innovations was said to cost just over $300 Australian annually compared to the CBR version which was closer to $750 Australian per year per unit over a 10 year period (2021). Many of these involved payments for subscriptions to the device rather than the actual hardware. The Utah State University (2021) project an overall saving in labour of around $612.75 per year, alongside over $7,000 in water savings per year. Whilst this may be attractive to a large irrigation enterprise, it is not effective for this project which aims to utilise more than 30 sensors to evaluate the effects of compaction variability on irrigation performance.

The next line of research found an Australian developed autonomous irrigation advance measurement system. This was completed at the Centre for Agricultural Engineering at

UniSQ Toowoomba campus. They have utilised a cost effective sensor setup that was tested over 5 seasons boasting a low cost setup and 6 month battery. The sensors were developed n by Foley et al originally in 2015 named the Taggle IrriMATE advance sensors and were integrated with SISCOweb technology to relay real time irrigation data to a phone app . This is extremely appealing for full time applications on farm however for the purpose of the research to be conducted the design of the sensor is more important. They chose to utilise low cost moisture probes with an Arduino microcontroller transmitting through a taggle system. This taggle tower would allow for data collection even in some of the most remote farms in Australia. Ultimately there is evidence that advance sensors are in development however there is a lack of research surrounding multi furrow advance sensors. This would be greatly important for measuring the advance wave across many different furrows simultaneously.

2.9 SUMMARY OF KEY LEARNINGS

The performance of surface irrigation is dependent on a range of factors, some of which vary on temporal and spatial scales. One of the most important factors influencing surface irrigation is the infiltration rate which is determined by soil properties. Furthermore, the soil type and composition has a prominent influence on the water holding capacity and infiltration rates. Prior basic research experience in this area has revealed the influence of clay content on the ability to retain moisture. Research supports that smaller particle soils (predominantly silt and clay) have a higher water holding capacity when compared to sandy soils (Ball, 2022). This continues to find sandy soils for renowned for faster and higher infiltration rates. This is a general rule however the exact values for the testing to occur should be considered given how rapidly soil characteristics can varying from point to point.

This will influence the methodology and particularly the locations for the testing to follow. The main goal will be to analyse the variability that occurs in area of compaction particularly on the tramlines and the planting furrows.

As discussed previously throughout the literature review section, there are many research papers that have been published surrounding the chosen project. Although they do not align directly with the scope of this project, they provided a range of results and recommendations that can be factored into the methodology. One of the most important learnings from the literature reviewed is the overall accuracy and value of utilising SISCO (Surface Irrigation Simulation, Calibration and Optimisation) tool. The hydraulic modelling tool is proven to be one of the effective open channel flow irrigation simulation systems. It has the ability to account for a wide range of temporal parameters including inflow rate variation, surface roughness, slope, furrow geometry and soil infiltration rates. The results from the research illustrate its value to be used in numerically and graphical presenting the irrigation event. This will be a value asset to potential utilise in the project methodology, to evaluate the flow of water of time and ultimately overall efficiency.

Although the literature has not directly addressed or recommended other methodologies for projects of such nature, they touch base upon the importance of controlling the test parameters as best as possible. The results from the literature review illustrate how surface irrigation systems have a major tendency to vary from time to time. It also recognised that the cracking clay soils in the surrounding darling downs area are more likely to see a variation in application efficiency when compared to other soil types. Ultimately this denotes that my testing should occur across multiple tramline, planting track and normal furrows as it will improve the accuracy of results and reduce any data discrepancies in the testing.

2.10 CONCLUSION

The literature review has provided an overview of all aspects related to the research of field variability in surface irrigation settings. Furrow irrigation will be the focus of the research with the literature review revealing that it is perhaps the most widely used methods in Australian agriculture. As a result, the research will be of greater importance to farmers and researchers in agriculture. It was also discussed that SISCO is the most appropriate and accurate modelling software for use in the data analysis. The software has the most user friendly interface with high degree of accuracy, but most importantly it has features for optimisation and also multi furrow analysis. This will be of great value when measuring and evaluating multiple furrows. As described the project will be investigating furrow performance with variable levels of compaction. This ultimately means that data will need to be collected from multiple furrows for comparison and validation. Compaction is a large issue throughout Australian agriculture in particular with large machinery leaving major footprints in the field. Particularly the project will aim to measure the effect of machinery compaction so that an optimised strategy can be developed. As discussed throughout the review this project will require the development and adopting of advance moisture sensors. Ultimately the reviewing of prior research has been valuable in guiding the direction of the project to ensure that it is both achievable and applicable to Australian irrigation.

CHAPTER 3 DEVELOPMENT OF ADVANCE FURROW SENSORS

3.1 SENSOR REQUIREMENTS

This project utilises SISCO software to effectively model and evaluate the efficiency and effectiveness of an irrigation event. The software requires many different measurements to compute some of which include the flowrate, furrow dimensions and field slope, however the most crucial is the advance wave measurements. The advance wave is the movement of water down the length of the furrow, by measuring the advance it allows SISCO to calibrate the infiltration characteristics and produce accurate results. It is therefore important to develop a sensor that can record the time at which the water reaches a certain distance along the field. The sensor was developed to meet the following requirements:

- Able to detect water movement down a furrow
- Withstand field conditions (extreme weather events and high temperatures)
- Transmit information in real time to a storage device of some description.
- Easy setup and handling of equipment
- Run for multiple months on a singular battery
- Transmit a minimum of 5km

This aspect of the dissertation was completed in conjunction with the Centre for Agricultural Engineering which have provided the materials and facilities to build advance furrow sensors. The design has been uniquely developed by the CAE for measurement of a small pipe through the bank furrow irrigation system and was utilised for this project also. Given that the dissertation is set to record the influence of compaction variability on irrigation performance, many sensors were to be built and programmed. The old sensors were suitable for the project to be conducted however their age was showing potential problems. As a result, this meant utilising the preexisting design with upgraded and new parts in greater quantity, particularly to measure data across multiple different furrow simultaneously.

3.2 METHODOLOGY AND TECHNICAL SPECIFICATIONS

As mentioned above this project required the construction of advance sensors. The aim was to capture spatial variability which would require a sufficient number of sensors to monitor multiple furrows. The project requires multiple furrows to be measured simultaneously. The main furrows to be analysed will be the tramlines which experiences compaction from the self-propelled sprayer and the tractor. This will be compared to normal furrows which are the uncompacted. Furthermore, it would be valuable to quantify the effects of low compaction furrows which may include the planting tracks which only receives compaction from the tractor and not the sprayer. This will allow for bettering understanding of any relationships that may present themselves. It was determined that 6 furrows would be investigated with 2 tramlines, 2 normal/uncompacted and 2 planting tracks. The idea of having 2 for each level of compaction is ensure that the data returned from the trials is accurate and is better for validating the relationships found between compaction and irrigation performance. Each furrow will also require approximately 6 advance sensors spread evenly throughout the length of the furrow to collect data on the advance wave movement. Altogether that means that 36 individual advance moisture sensors would be required for the project.

The advance sensors consist of three key elements: the moisture sensor component, the microcontroller and the signal transmitter. These components together provide the ability to detect water arrival down a furrow and to transmit the data to an intended location for storage. The moisture sensor part can be relatively simple and economical however the cabling must be insulated from the water and soil particles. This will require a rating of IP67 which means that it is dust tight and also able to be immerse in water up to 1m depth (Clarion UK, 2024). The in microcontroller will not require much computing power, just need to identify changes in electrical conductivity through the moisture probe and relay through triggering of tamper wires. It would be more beneficial for the microcontroller to relatively small which would allow for easier storage and energy efficient to increase the life of the sensor field operation. The final aspect is a signal transmitter that must be able to transmit for a minimum of 5km in a timely manner to a taggle tower as many of the farms are greatly spread out. The transmitter will also be exposed to many of the elements meaning that it must be rated to at least IP64 accounting for dust and rain. Finally, there will be a housing unit that will need to protect the microcontroller part with a rating around IP53 also. This will stop most dust but more important rain that comes in from angles up to 60 degrees from vertical. The entire system will also be required to withstand temperatures between -5℃ to 50℃ for usage in the Darling Downs area and also run completely off battery power. This is the outline of the minimum technical specifications required for the building of advance moisture sensors. Below in table 3.1 is an outline of the components that meet the criteria above and were used for the project sensor building.

Table 3.1 Product for the construction of the advance moisture sensor developed by Centre for Agricultural Engineering.

Part Name	Quantity Required	Additional Comments
Duinotech Arduino Compatible Soil Moisture Sensor Module	36	-
RS PRO Grey PUR Potting Compound	2 x 500g Bag	May require more or less dependent on situation
Twin Core 5mm Electrical Cable	Minimum 43.2 metres	1.2m each sensor
Wooden Garden Stake 22mmx22mm	36 x 400mm	1 per sensor
Taggle SP3C Pulse Counter	36	-
PVC20 20mm CAP HOLMAN	36	-
HOLMAN PVC 40mm Diameter	36 x 300mm	-
HOLMAN PVC Pressure Reducing Coupling 40mm to 25mm	36	-
Arduino Pro Mini 2	36	-
Custom Printed Circuit Board	36	Must be able to hold 9V battery
9 Volt Battery	36	-
Assortment of Assembly Nuts and Bolts	108	3 per Sensor

3.3 CONSTRUCTION OF ADVANCE SENSORS

The moisture sensor aspect of the build is picture below in figure 3.1, the methodology for constructing this involved attaching a standard moisture probe to a standard twin core automotive cable and using a cable potting resin compound with a PVC casing. The cable is set to be at least 1 metre in length to allow the moisture probe to be placed in the furrow whilst the rest of the electronic components are suspended away from the water. The potting resin generally requires around 24 to 48 hours to dry completely and then is readily available to be submerged.

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Figure 3.1 Visual depiction of integrating moisture probes into PVC casing for advance furrow sensors.

The above component provides the ability to recognise the water movement along the furrow. The information is required to be recognised by utilising an Arduino Pro Mini 2 microcontroller. The Arduino is uploaded with a highly specific code that was developed by the Centre for Agricultural Engineering and utilised for this project. The exact code is attached at the bottom of the document in the Appendix A, in simplified terms the Arduino will activate in 2 minute intervals to effectively check if there has been an increase in the electrical conductivity on the moisture probe. The probe uses an increase in soil moisture instead of a fixed soil moisture content trigger. The use of the increase rather than a fixed value means that the sensors should still function if the soil around the probe is moist. The use of the increase also reduces the issues associated with the inaccuracy of the low cost soil moisture sensor.

The 2 minute interval can be manipulated simply, altering this value can provide a more accurate timestamp however risks using more of the battery capacity thus the value remained as predetermined. Once the increase in soil moisture has been detected the Arduino code sends a signal through the trigger contacts on the circuit board. The transmission component is completed by a Taggle Systems Pulse Counter. This is the device attached to the white cable below in figure 3.2. The taggle device operates by transmitting a signal when the tamper cables are connected as a result of the Arduino microcontroller. The Taggle Pulse Counter (Taggle 2023) is designed to transmit flow pulses from household water meters on an hourly basis. This hourly read rate is too infrequent for use as an advance sensor. The Taggle counter also includes a set of tamper wires which transmit a signal immediately if it is removed from the water meter. Connecting the tamper wires to the Arduino board means that it is possible to send the water advance signal immediately once the water has been detected. The transmission from the Taggle counter is unidirectional. It is satisfactory in terms of IP rating and also is claimed to transmit signals from 5 to 30km in rural areas.

The signals from all Taggle counters are transmitted to a single taggle receiver tower which was installed temporarily on the research farm. The Taggle receiver tower communicates back to a central server via a mobile phone network connection. This data can be downloaded from the Taggle servers. The completed setup of the sensor is depicted in figure 3.2 with the 3 operational components attached.

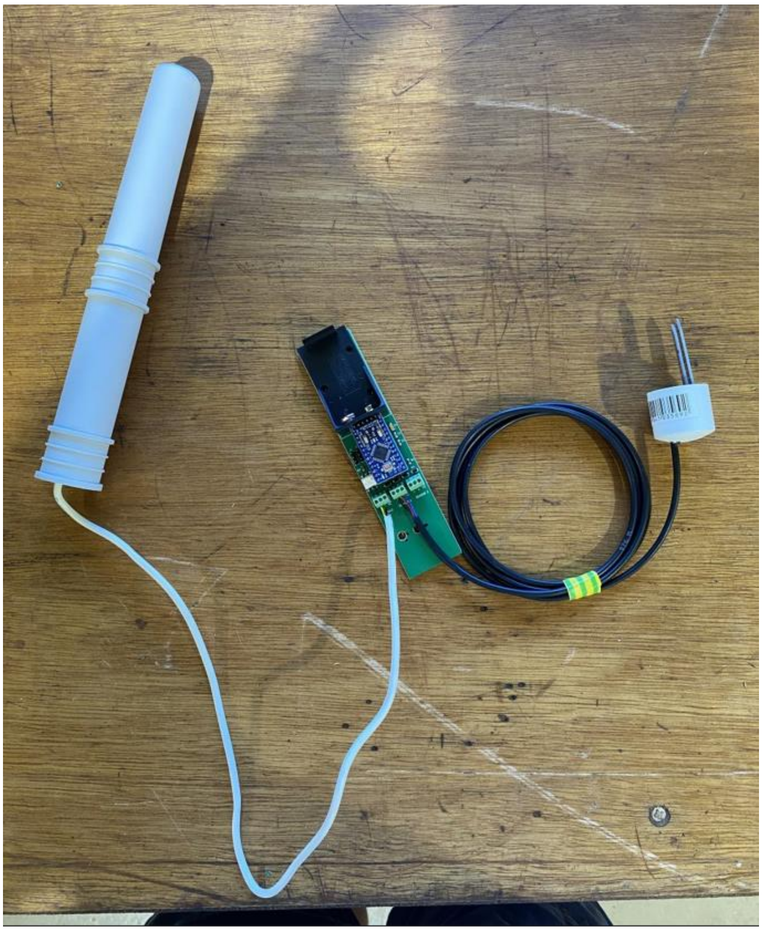


Figure 3.2 Assembled moisture probe and taggle alert system with Arduino pro mini circuit board.

Whilst the main components have been assembled it is crucial to upload the code from a computer as outlined in Appendix A and conduct preliminary testing on the sensor. Whilst there was no taggle tower available at the University of Southern Queensland Toowoomba campus, the testing could be completed by testing to see if the tamper wires were triggered by the Arduino. More specifically, this was completed by placing the moisture probe in a container of water and placing the digital multimeter probes on the connection part for the taggle transmitter. This is completed on the continuity setting where the machine would beep in the event that the tamper was triggered. The preliminary testing was conducted extensively across all advance sensors as per figure 3.3 below.

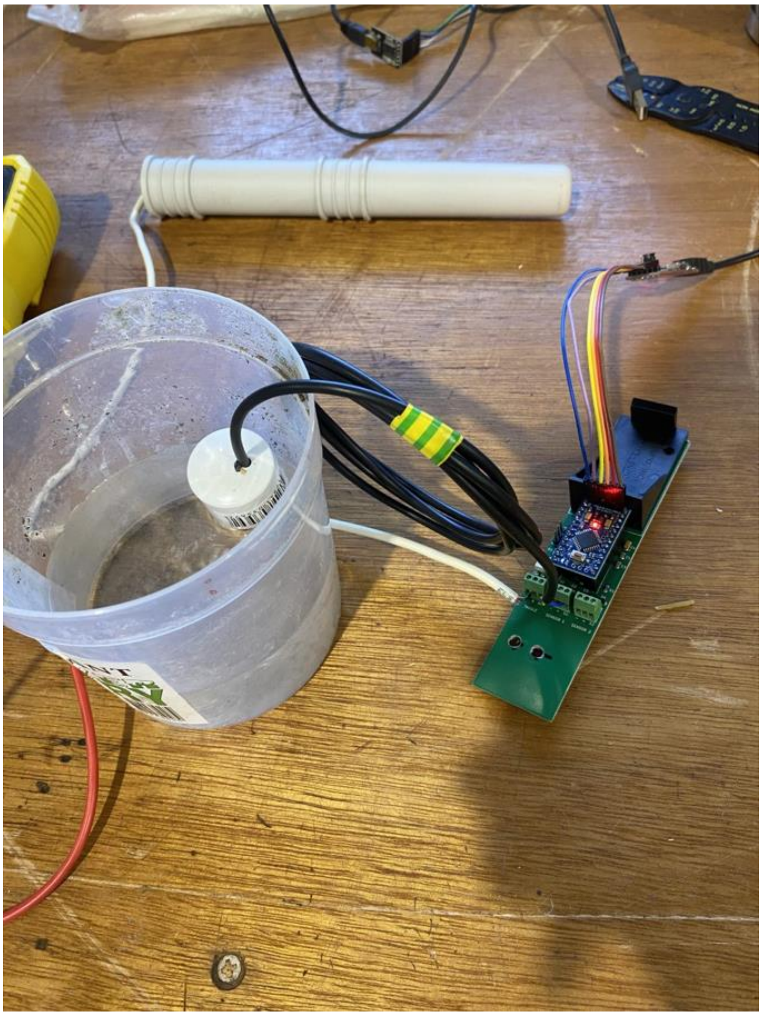


Figure 3.3 Uploading of Arduino code to control moisture sensor from computer and testing device for response in a container of water.

Upon passing the preliminary testing, the components can be placed in a housing unit that can protect it from the natural elements. For this project the housing unit consisted of a wooden stake that would be placed in the ground to keep the unit upright connected to a section of PVC that would store the microcontroller and battery section whilst allowing for the moisture probe to come out the bottom side and be placed in the furrow. The top part consists of a simple PVC tubing cap with the taggle system sticking upright to transmit the data. Numerous examples of the assembled sensors are pictured below in figure 3.4. The main goal of the housing unit is to weatherproof the electrical components, with the design endorsed for short research periods rather than seasonal work.

Figure 3.4 Final encasing of electronic components in a PVC housing unit connected to a wooden stake to position in the field.

3.3 EVALUATION OF SENSOR SUITABILITY

In a simplistic manner the sensor is suitable for usage in the field trials. It has succeeded in fulfilling the project requirements and can effectively detect water and transmit to a device in real time. Communicating information with a time stamp is imperative to tracking the advance wave movement along the furrow. This sensor developed through preliminary tests can directly relay information into SISCO to calibrate the soil infiltration characteristics and will be used to evaluate the irrigation performance. Whilst basic in their development and housing unit, the sensor developed for this project is suitable for the intended task.

3.4 SENSOR IMPROVEMENTS AND RECOMMENDATIONS

As mentioned, the sensors have undergone testing that has proven their ability to detect water and also in the transmitting of information. There are however many future recommendations that could improve the overall usefulness and effectiveness of the system. One of the most relevant recommendations would be allowing for measuring of multiple furrows simultaneously. This was considered for the project however limited time affected this. By measuring multiple furrows, it would reduce the need for 36 individuals sensors and could instead have multiple moisture probes that relay to one microcontroller and transmitter. This would be ideal for this project where multiple furrows are being measured during the one irrigation event. There could also be further development into the detection of the recession wave where the moisture probe is able to recognise when the water retreats from that part of the field. This would be a useful aspect in validating the SISCO simulation.

Another future improvement could include integrating a 4G module to directly link to the service rather than utilising the taggle system. The advantage of the taggle system however is that it allows for research to be conducted anywhere that the taggle tower is positioned rather than relying on service of which not all farmers have. This however relies on the fact that there is a taggle tower in close proximity. With the constant upgrading of cellular service throughout Australia, it would definitely be worth considered the adoption of a 4G module for data transmitting. To conclude the sensor is considered viable for this project and has the ability to be integrating directly with SISCO Web to record and analyse data in real time.

CHAPTER 4 FIELD METHODOLOGY

4.1 INTRODUCTION

This section provides a general overview to the methodology process for the testing of surface irrigation variability. There are key prior learnings that influence the methodology decisions, the materials/equipment/site requirements for the project and the procedure in itself. Many influencing factors to the methodology were identified in the relevant review of literature to assist in the selection and development of the most appropriate approach. There is also details of the risk assessment that has been completed as a part of the project prior to initial testing. The basis of the methodology for testing is outlined throughout the below literature, tables and figures. The important aspect for this research is to consider the effect of compaction on the movement of water, thus the project methodology is aimed at placing sensors in tramlines, planting tracks and uncompacted furrows to gain a better overall perspective. Upon the conclusion of the irrigation event the sensors are able to be collected from the field ensuring that the specific locations are recorded beforehand. It is also important for the SISCO data analysis that the average field slope, field length, inflow rate and furrow configuration are effectively mapped and recorded to be used in the calibrations. The collection methodology of all data related to the project is outlined below.

4.2 FIELD SELECTION

The project to be completed requires a research site that fulfils the specific criteria. The first major aspect is the that chosen location for testing requires a large surface irrigation field with particular interest in using furrow irrigation systems. This will require collaborating with a grower to allow for the project and testing to be undertaken on their property simultaneously to an irrigation event. The location should also be relatively local to the university to reduce the level of input required to complete the project. Given the extent of the task, communicating with the Centre of Agricultural Engineering (CAE) has proven to be very beneficial in the site selection and preparation process. With their assistance Struanville Farming Co located south-west of Bowenville in Queensland were happy to facilitate the research on their property. This location upon initial inspection appeared to be appropriate for the testing to occur.

The soil testing for this project has been limited in simplicity, with the aim to provide a brief overview as to the soil characteristic for the test site. Upon interviews with the farming management team, it was found that they had previously completed soil tests through Nutrien Ag company detailing particularly the soil nutrient requirements however it also revealed the soil type. As expected in the Darling Downs region much of the soil was determined to be medium in clay content and labelled as black vertosol soil. The detailed results from the previous testing in early 2024 are found in the Appendix C. This is a common soil that is irrigated with cotton, corn and sorghum throughout southern Queensland and thus the results will be relatively reflective of the region. Figure 4.1 below illustrates the field conditions at Struanville Farming Co where the testing is set to occur. The project has employed these soil profile results testing and description from the Australian standards to improve credibility and overall data reliability.

Figure 4.1 Image of field that satisfies all criteria, located at Struanville Farming Co.

4.3 SITE AND SETUP OVERVIEW

With the site selected at Struanville Farm, the next major step was to collect information on the general field setup. This particular field had a corn crop that was planted in the middle of August and had been pre watered. This field can be seen in a bare state in figure 4.2 from a satellite image. The red box on the left hand side outlines the area that the sensors observed in figure 4.4 were set to be placed. This side of the field was the furthest downstream from the head ditch which was along the top of the figure. With the road access just beside this made it relatively easy and simple to access and layout the advance sensors. This section of the field had been drawn up in a diagram (figure 4.3) which illustrates a rough outline of the setup. Communicating with the management team at Struanville farming found that they used tramlining management practices where the machinery would only travel down particular furrows to reduce the overall compaction on the field. More specifically they had tramlines spread 24 metres apart with planting track furrows 12 metres apart in between, with furrow 2 metres apart. It was decided with assistance from farm management that the compaction would be most variable across the tramlines and the planting tracks. This ultimately led to the setting out of sensors down these furrows. For background context the corn was planted with two rows on each of the ridges between the furrows at 1 metre spacing. Finally, the farm also revealed that they still irrigated using siphons that would be started out of the head ditch and collect water in the tail drain to be pumped back into the dams. This is all exemplified throughout figure 4.3 below.

Figure 4.2 Satellite image of Struanville Farming Co field '2A', with the sensors in the red quadrant of the field spaced out at the desired distance apart.

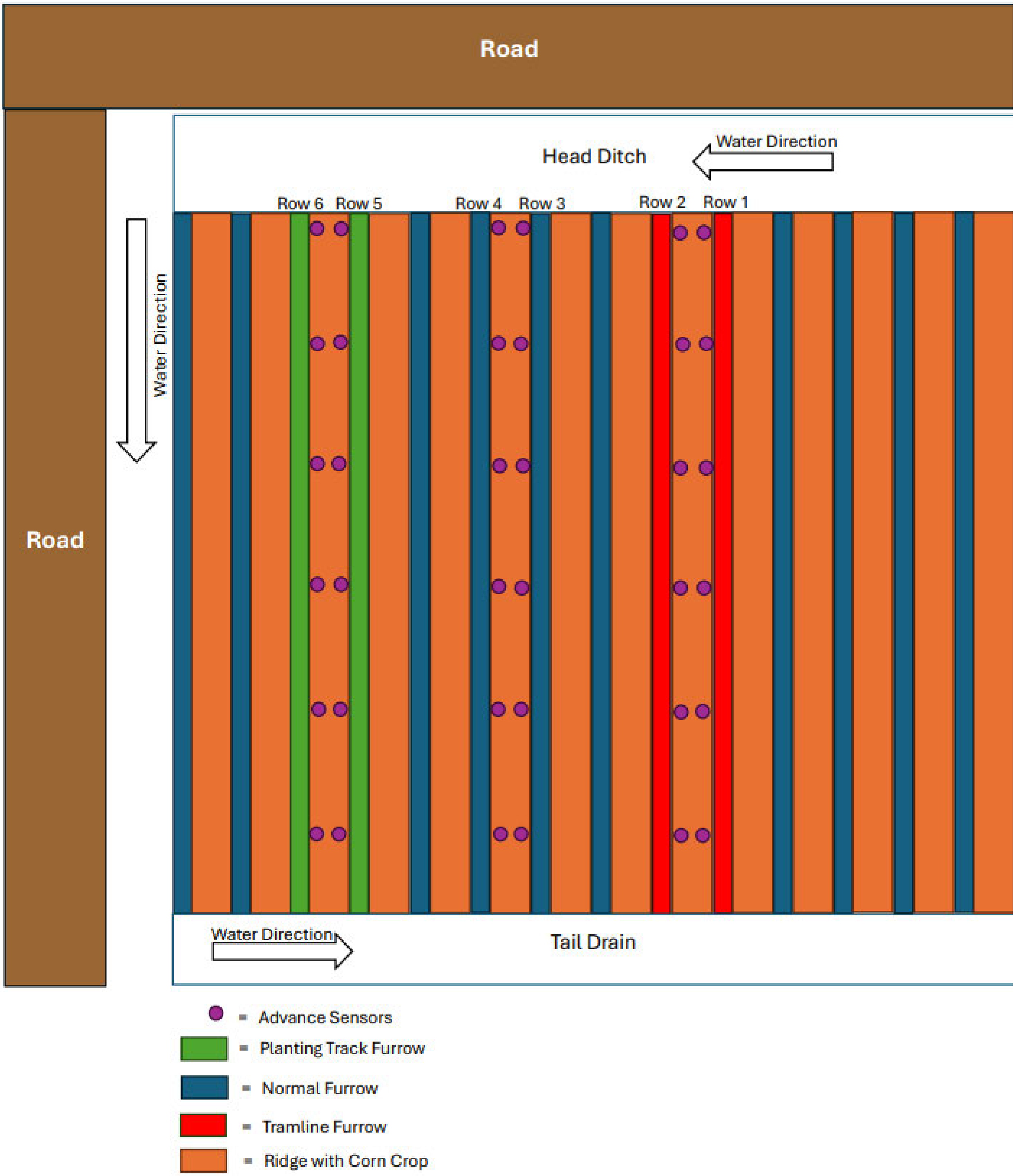


Figure 4.3 Diagram of red outline area of figure 4.2 to show sensor and field setup (not to scale).

Figure 4.4 Placing of batteries in a total of 35 sensors that were utilised for the field testing at Struanville Farming Co.

Figure 4.5 Setting out of advance furrow sensors along tramline, normal/uncompacted and planting furrows at given distances.

4.4 FURROW DIMENSIONS

A key parameter required by the SISCO software for analysis to occur is a generally outline of the furrow dimensions. Figure 4.6 below provides as a detailed description of the four key measurements required to be measured and input into the system. They include the Top Width, Middle Width, Bottom Width and Maximum Height as outlined. It is important to note that the SISCO can adopt a variable furrow geometry over the length of the furrow however the furrow dimensions has limited impact on the behaviour of the irrigation and thus only one measurement was taken across each furrow.

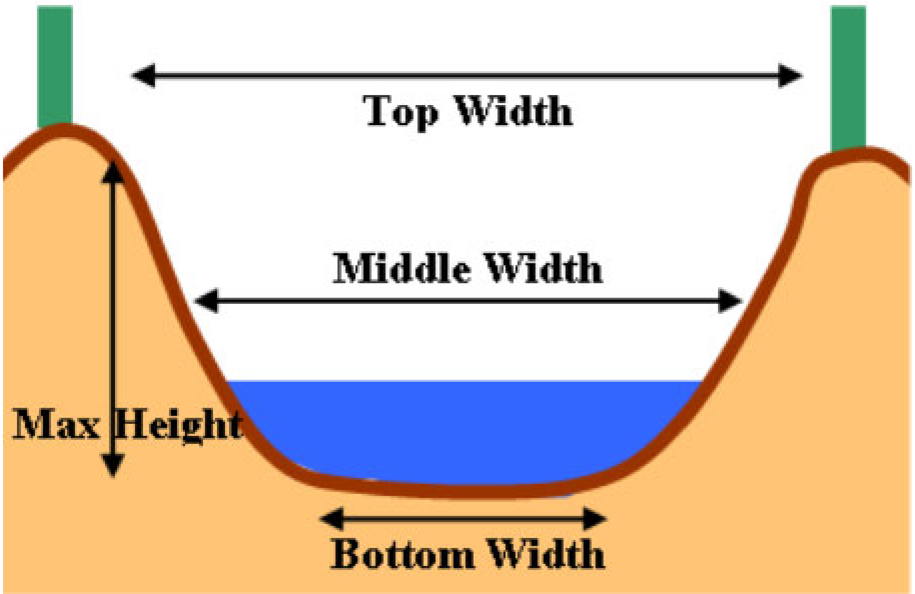


Figure 4.6 Outline of furrow dimensions requirements for SISCO software.

The field methodology for the particular project involved utilising a staff which was levelled across the top of the furrow as per figure 4.7 below. The staff had measurements on it which was used to collect the measurements for the top, middle and bottom width. A tape measure was employed to collect the max height value for the individual furrow. Although the furrow dimensions will have very minimal impact to the results it was still crucial to gain a values reflective of each furrow.

Figure 4.7 Image from field of level staff for assistance in measuring furrow dimensions.

4.5 FURROW SLOPE

The furrow slope is a crucial factor that can affect the rate at which water moves down the furrow ultimately impacting on the overall level of infiltration. The methodology for collecting the furrow slope data was relatively simple yet effective in nature. A dumpy level, tripod and staff were measurement tools for collecting the slope of the field as per figure 4.8. More particularly the dumpy level was setup around the halfway point approximately 225 metres down the furrow and directly off to the side by approximately 20 metres. With another set of hands present the staff measurement was taken at the start and every 20 paces along the furrow. Although many data points will be taken from this methodology that main aspect is to take the height measurements at both the start and end. This allows for finding the average slope across the length of the furrow which can be entered into SISCO software. The extra data points will ensure that there are no major discrepancies along the length of the furrow to that of the results expected. This was also only completed for one furrow given that the process is extensive and takes time, it is assumed that all furrows have a very similar slope value.

Figure 4.8 Example of dumpy level, surveying staff and tripod used to measure field slope.

4.6 INFLOW RATE

Inflow is a major variable factor that influences the effectiveness and efficiency of the irrigation event. Thus, the methodology was relatively intense will many measurements taken at differing times. The first major aspect for determining inflow rate is understanding the dimensions of the siphons that are used in this particular field at Struanville farm. Figure 4.9 below illustrates one of the siphons used, with the length and inner diameter the two crucial measurements taken. It was therefore assumed that the siphon dimensions remained the same across all other furrows.

Figure 4.9 Image of siphon used at Struanville Farming Co to transfer water from head ditch to each furrow.

Whilst the siphons play a crucial part in determining the flowrate of each furrow, it is a particularly hard aspect to measure directly, even more so when there is environment changes resulting in fluctuating results. Research prior has revealed that there are siphon integrated flow meters developed to measure the changes in discharge directly, however they unavailable for usage across the six different furrows in this project. Therefore, the methodology for collection of data pertaining to the flowrate included utilising key hydraulic principles. This involved utilising the concept of hydraulic head, this is referred to as the value that quantifies the amount of potential energy that is stored in a water system (Energy Education, 2018). In this methodology it is referring to the difference in head or hydraulic pressure between the head ditch and the start of the furrow. Figure 4.10 below provides a visual depiction of hydraulic head within a siphon fed surface irrigation system. As seen the main goal is to measure the difference between the height of the water in the head ditch compared to the start of the furrow. The figure illustrates that the measurement of the head occurs when the clear pipe is placed into both bodies of water with the pressure causing the water to rise until its level with the head ditch. The value is generally measured in millimetres and can be used to calculate the flow rate.

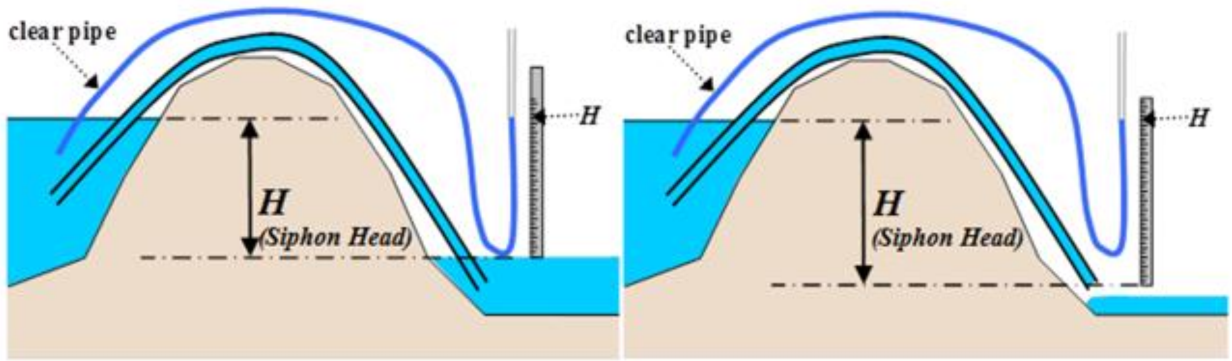


Figure 4.10 Illustration of hydraulic head within a siphon fed surface irrigation system taken from SISCO (Gillies, 2015).

Figure 4.11 Using concepts of hydraulic head in measuring instrumentation to calculate flowrate for each furrow.

To measure this important data, a device was employed from the Centre for Agricultural Engineering that employed this principle to measure the difference in millimetres. This device is picture in figure 4.11 above. The apparatus consists of a small electric pump, two even clear pipes for observational purposes and two smaller black hoses that could reach into the head ditch and also the start of the furrow. An important aspect to the implementation of the measuring instrument is to calibrate it correctly. This meant using the electric pump to suck water from a bucket up into the observation section ultimately pushing the air out. Once the waters are level the apparatus is successfully calibrated. It is crucial that there is no air leaks at the top near the motor as the water will recede back into the bucket if that is the case. Submerging a black tube into the head ditch water and the start of the furrow water as per the figure below triggers change in pressure and movement in the device. The amount of hydraulic head can then be record as a measurement of the difference in water height. This is exemplified in figure 4.12 where the difference is approximately 230mm. The measurements were taken across different times throughout the irrigation event and completed for each of the six furrows under examination. This hydraulic head is the only field data required to be measured in regard to flow rate however the process requires more mathematical procedures to find the discharge in a rate of litres per second (L/s). The WaterPak (CRDC 2012) provides farmers with a guide that provides theoretical flow rates for siphons based upon head measurements. They provide an irrigation toolbox with a table of pre-solved data for operating head measurements dependant on siphon diameter and length. With the intention of maximum accuracy, an equation developed by Bos in 1989 can be used to find the exact flow rate value. The equation used is:

$$Q = \frac{\pi D^2}{4}\left(\frac{2g\Delta h}{1.9 + \frac{fL}{D}}\right)^{0.5}$$

$$Q = \ Discharge\ (\ m^3)$$

$$D = \ Siphon\ Internal\ Diameter\ (m)$$

$$g = \ Acceleration\ Due\ to\ Gravity\ (9.81 m/s^2)$$

$$\Delta h = \ Operating/Hydraulic\ Head\ (m)$$

$$f = \ Friction\ Loss\ Coefficient\ (assumed\ to\ be\ 0.019)$$

$$L = \ Siphon\ Length\ (m)$$

Figure 4.12 Image of the difference in head for a furrow to calculate the individual flowrate.

4.7 ADVANCE MEASUREMENT

As outlined in the previous chapter this project was conducted with the assistance of advance moisture sensors that were built for these research purposes. A total of 35 were made available for usage in the field trial. The devices were initially placed in the each of the desired furrows as close as possible to the head ditch to indicate when the irrigation event had started. Given that the owner had provided information that the length of the field according to their autosteer system was 450m it was decided that the sensors would be placed approximately every 80 metres. This is illustrated back in figure 4.3. To complete this a walking application was used on the phone to track the placement as close as possible to 80 metres apart. After the placement for each advance sensor in each of the tramline, normal/uncompacted and planter furrows, the GPS position was taken for later calculations to know the exact distance along the length of the furrow. This is important to get them as accurate as possible as it can influence the competency of results when used in SISCO. Table 4.1 below provides an overview to the field approximate distance along furrow and the measured GPS positions of each. The exact distance was then calculated using a developed MATLAB code derived from Veness (2019) which turned the GPS coordinates into a distance value in metres. Veness (2019) employs the 'haversine' formula which calculates the circular distance between two points assuming there is no variation to the surface level such as hills or valleys. The exact MATLAB code employed can be found in Appendix B. This is displayed in the far right column of table 4.1.

Another important aspect is outlined in table 4.2 which shows the GPS positioning of the Taggle tower setup which is shown in figure 4.13. This is not a crucial factor in terms of the SISCO simulation software however it provides background into its position and also ensures that the tower is in range of the sensors to transmit the critical data. Figure 4.14

below is a test conducted on the sensors to determine that they are operating, and that the data is being transmitted. This is a very important part of the methodology as the irrigation event can be missed if the sensors are not working properly. This was conducted by placing the moisture sensor probe in a container of water as shown. In the context of this project there was some predicaments that stopped the sensors from transmitting when initial field testing occurred. It was found that a magnet may be required to wake up the Taggle transmitter in the event that they had not been used before. It was also found that the Taggle devices required registration before they could transmit the data. Given that the irrigation event does not happen often during which the project is undertaken, it was essential to ensure the advance sensors were all in full operating condition.

Table 4.1 GPS coordinates in decimal degrees of advance moisture sensors and exact calculated distance along furrow.

Field Approximate Distance Along Furrow (m)	GPS Coordinates		Exact Calculated Distance Along Furrow (m)
	S	E	
0	-27.358375	151.365654	0
80	-27.35764	151.365779	82.11
160	-27.357004	151.365893	153.72
240	-27.35626	151.366012	237.27
320	-27.355531	151.366157	319.57
400	-27.354792	151.366276	402.57
450	end of row		450

Table 4.2 GPS coordinates in decimal degrees of Taggle tower.

	Taggle Tower GPS Position
S, South	-27.3527617
E, East	151.3525022

Figure 4.13 Taggle tower unit setup at Struanville Farming Co to receive and transmit advance data.

Figure 4.14 Field testing of advance furrow sensor to ensure that taggle tower is in range to transmit data.

After the placement of the sensors, the taggle transmitter identification number was to be recorded with particular respect to their distance along the furrow and which furrow they were located in. Table 4.3 shows what the taggle ID numbers recorded were, with a total of 35 sensors operating sensors it meant there was no advance sensor in row 6 (planting track) at the distance of 402.57 metres. This is not an optimal outcome however there is still plenty of data available from the other 5 sensors to produce accurate simulations in SISCO.

Table 4.3 Record of taggle device identification number kept along each furrow and at specific distances down the furrow.

	Row					
Distance Along Furrow (m)	**1 (TRAMLINE)**	**2 (TRAMLINE)**	**3 (NORMAL)**	**4 (NORMAL)**	**5 (PLANTER)**	**6 (PLANTER)**
0	90999	91012	91037	91027	91148	91161
82.11	91073	91009	91162	91160	91038	91016
153.72	91158	91041	91145	91171	91175	91089
237.27	91013	96836	91169	91154	91057	91005
319.57	91043	91176	91021	91128	91131	91129
402.57	91026	91029	91000	91034	91028	-

With the GPS coordinates and Taggle ID number recorded the taggle devices can be registered and named with the use of the Centre for Agricultural Engineering's Tagglert setup. This system is picture below in figure 4.15 which shows the webpage that allows the taggle to be named, provide associated phone numbers for recording data and the latitude and longitude of its position. As seen in the figure the naming convention includes the distance along the furrow in metres and the row that the sensor is located in. This webpage also allows for testing to see if the sensor has triggered recently. This was completed to assist with problem solving and utilised the read button on the top right side of the figure. This would produce a screen exemplified in figure 4.16 below where it illustrates the time of the last reading in UTC (Coordinated Universal Time), the value or number of times the sensor has been triggered and the tamper which refers to whether the sensors detect water. Testing occurred within the field to also ensure that the sensors were able to communicate with the taggle tower and ultimately with the 4G network. The data collected from the advance moisture sensors are crucial for the SISCO software to work effectively and thus is the reason for this extensive testing throughout the methodology.

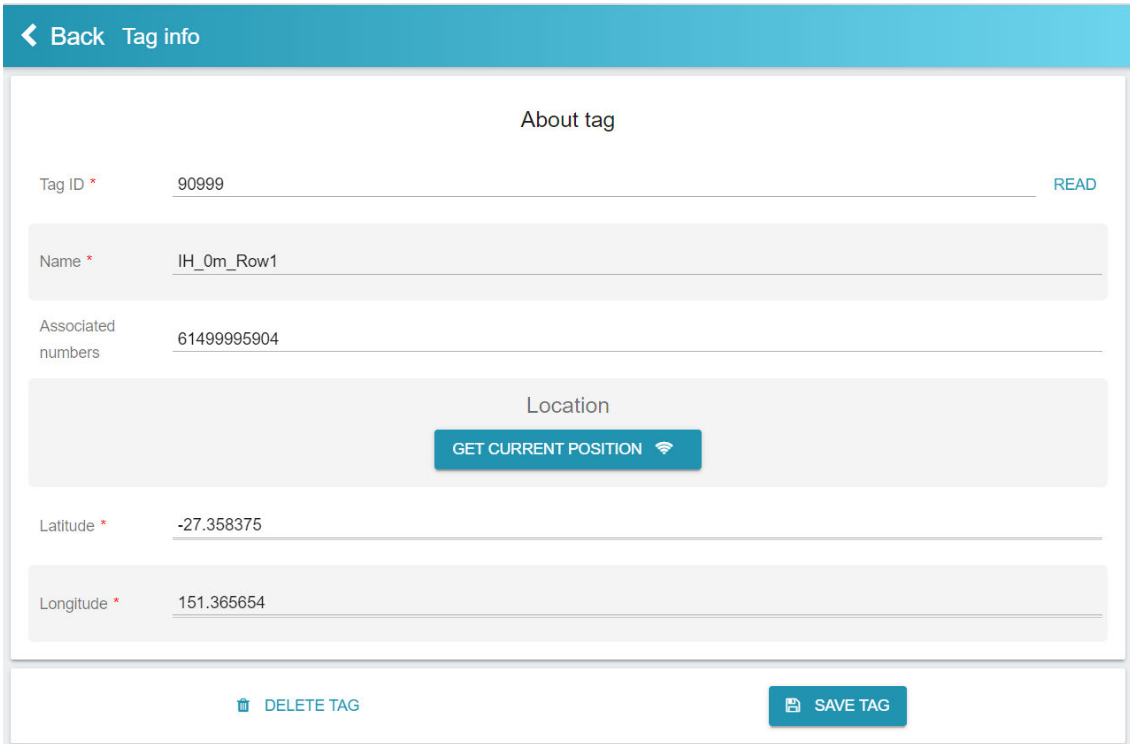


Figure 4.15 Using Tagglert to name and register each of the advance sensors to record data.

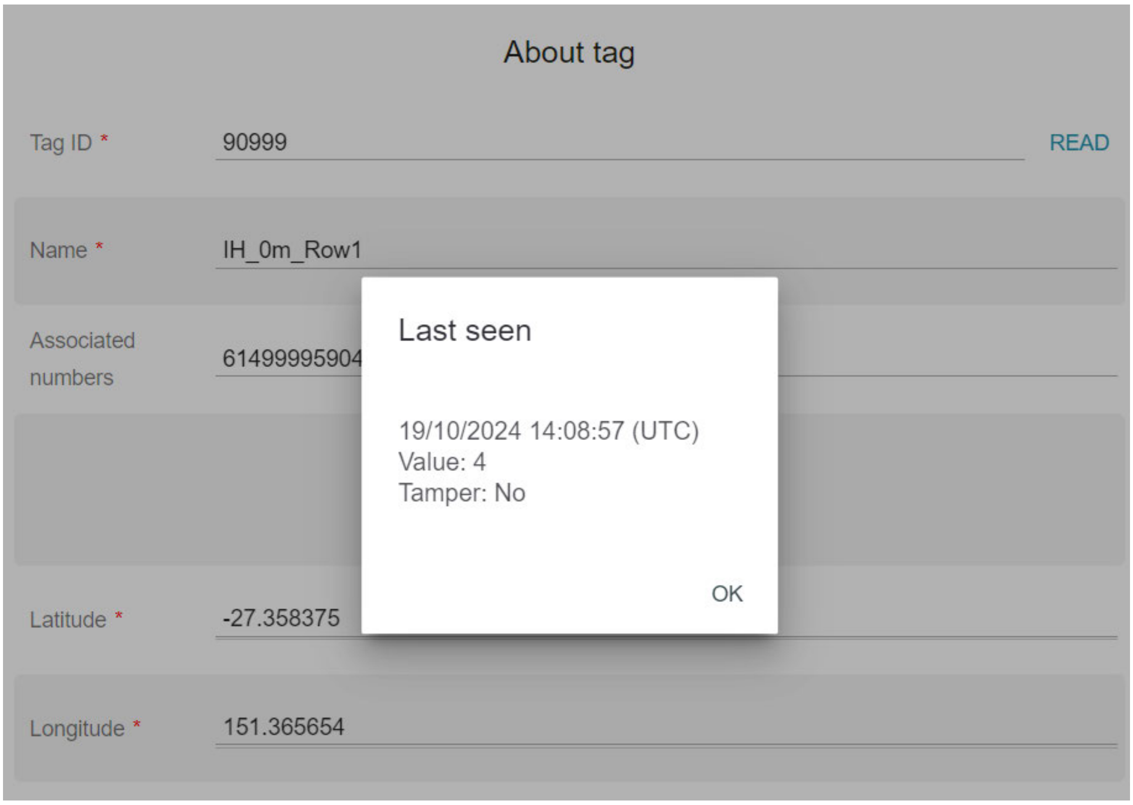


Figure 4.16 Reading individual taggle data to test for normal operation of sensors and time of last trigger.

Upon successful setup and testing of the advance moisture sensors, the irrigation event can occur. As outlined previously the sensors are staggered at a certain distance apart and as the water progresses down the furrow as illustrated in figure 4.17, the sensor will be triggered. This data is being recorded in various places such as SISCO Web, direct to contact phone number and also on the Tagglert website. It is important that the devices undergo continuous monitoring throughout the duration of the event despite the advance measuring process being automated. The advance sensors are also displayed in figure 4.18 and 4.19 demonstrating how the probe is set up in the furrow and the transmitter is installed besides the crop. The process is relatively intensive however it provides valuable and reliable results for later employment in the SISCO software for later evaluation.

Figure 4.17 Moisture sensor probe being submerged by the advance wave during the field trial.

Figure 4.18 A submerged moisture probe attached to the advance sensor housing unit to measure and record water movement.

Figure 4.19 Distribution of advance furrow sensors across tramline (left), normal/uncompacted (middle) and planting tracks (right).

4.8 SISCO

CISCO has been researched and chosen as the modelling software to be utilised for this dissertation. The data can be effectively analysed to produce a realistic animation of the water advance and infiltration over time as seen in the figures below. The most important calibrating factors are mentioned previously and have a profound impact on the data and the overall quality of the results. SISCO has however been proven to yield results of up to 90% accuracy through its sophisticated software development. Providing the software with accurate data will be the most important aspect for the methodology as a whole.

The first aspect of SISCO is to input the key parameters of the irrigation event that took place. Figure 4.20 below is a screenshot taken from SISCO to demonstrate what the input page looks like. There are many crucial elements in this section with the first being field details such as field length, manning n value and spacing between furrows. It is also important to adjust the slope to reflect what was recorded in the field this can be input as a variable over the length of the field or as an average slope value. The inflow data is also the next step with a cutoff time and inflow rate that can be constant, variable or calculated using the inbuilt function. The last of the essential elements for this project is the furrow shape picture in the top right of figure 4.20. The infiltration parameters are not yet addressed as the calibration stage is utilised to determine these values.

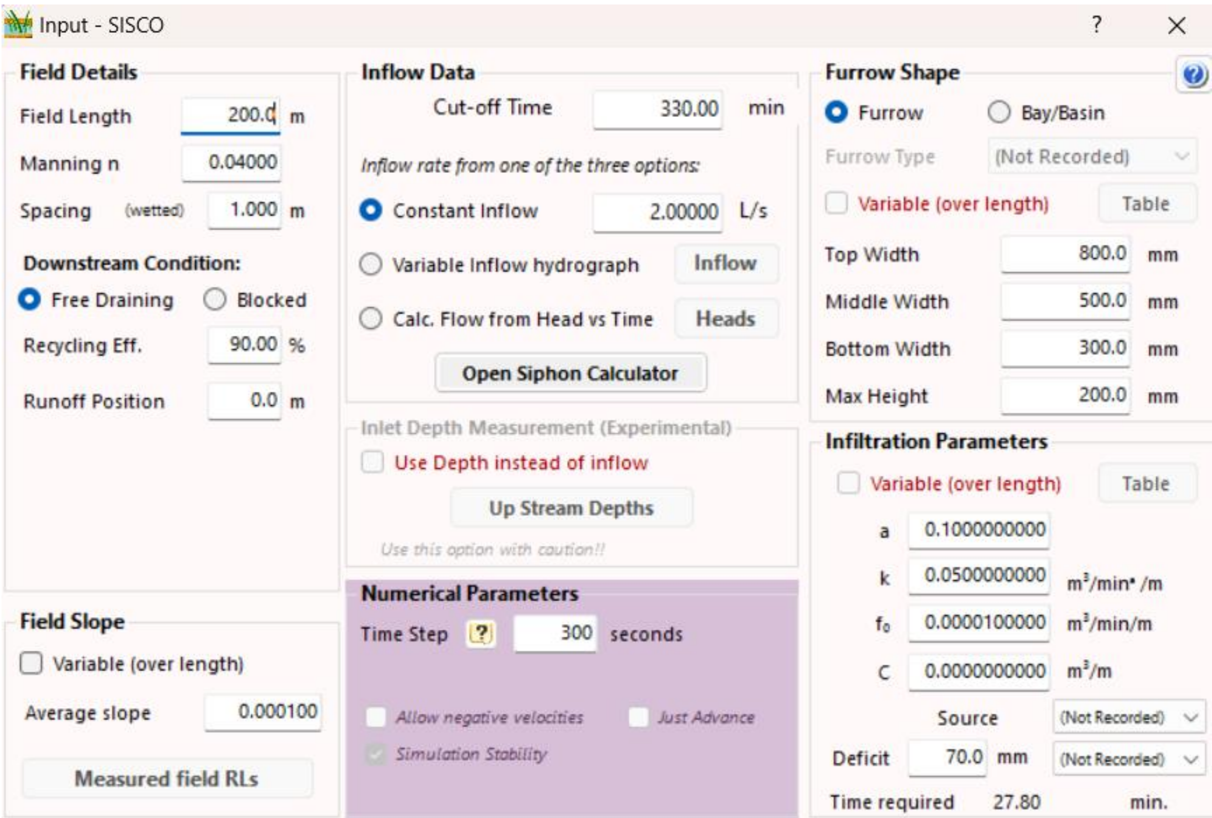


Figure 4.20 Example of SISCO input screen.

The calibration process is depicted in figure 4.21 below. This process is conducted to find values for the infiltration parameters a, k and f0. This is completed as per the figure below by inputting the advance data recorded from the field trial. By running the calibration SISCO will actively change infiltration parameter values to fit a curve to the advance data. There is also a section that shows the accuracy of the curve with most values yielding high accuracy. The calculated infiltration parameters can then be transferred to the input screen for simulation and modelling to occur.

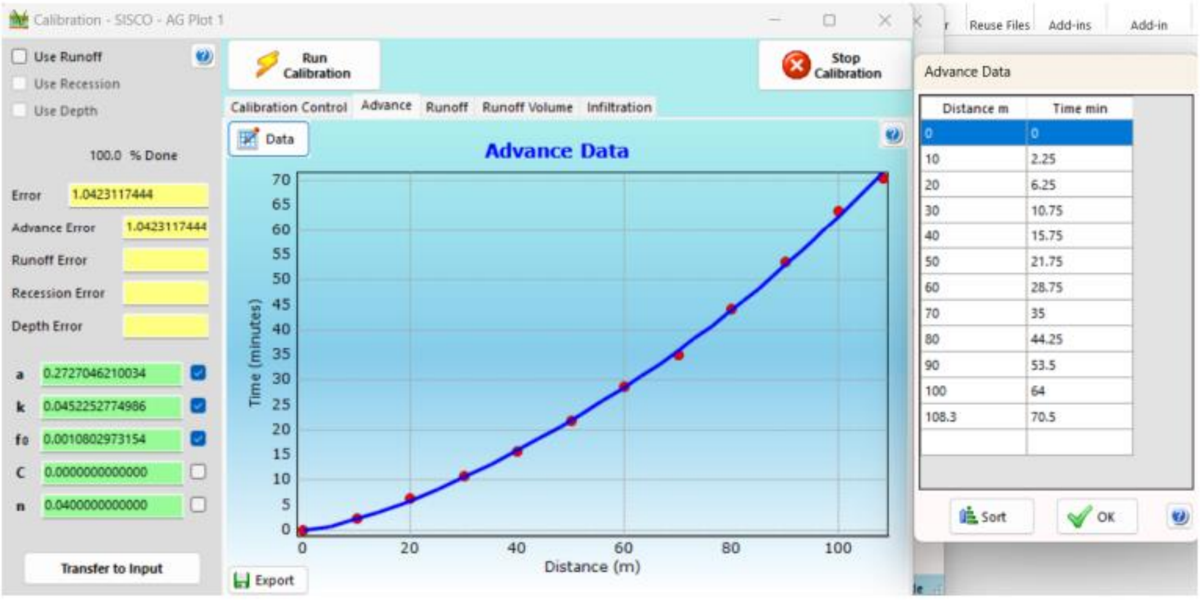


Figure 4.21 Example of SISCO calibration feature using advance data from prior research.

The modelling process is the final step in evaluating an irrigation performance. Upon the calibration of infiltration parameters and inputting of event details running a simulation will result in a page that looks like figure 4.22 below. This is an example of the infiltration animation that plays illustrating the infiltration over the period of the irrigation event. Furthermore figure 4.23 shows the results page that can also be accessed through the modelling process stage. This results page includes many of the key performance measuring indicators with application efficiency, requirement efficiency and distribution uniformity some of the most important. The simulation also yields a variety of other graphs that include the infiltration, runoff and advance. Overall, the SISCO software is relatively simple to use and is highly accurate at evaluating irrigation events.

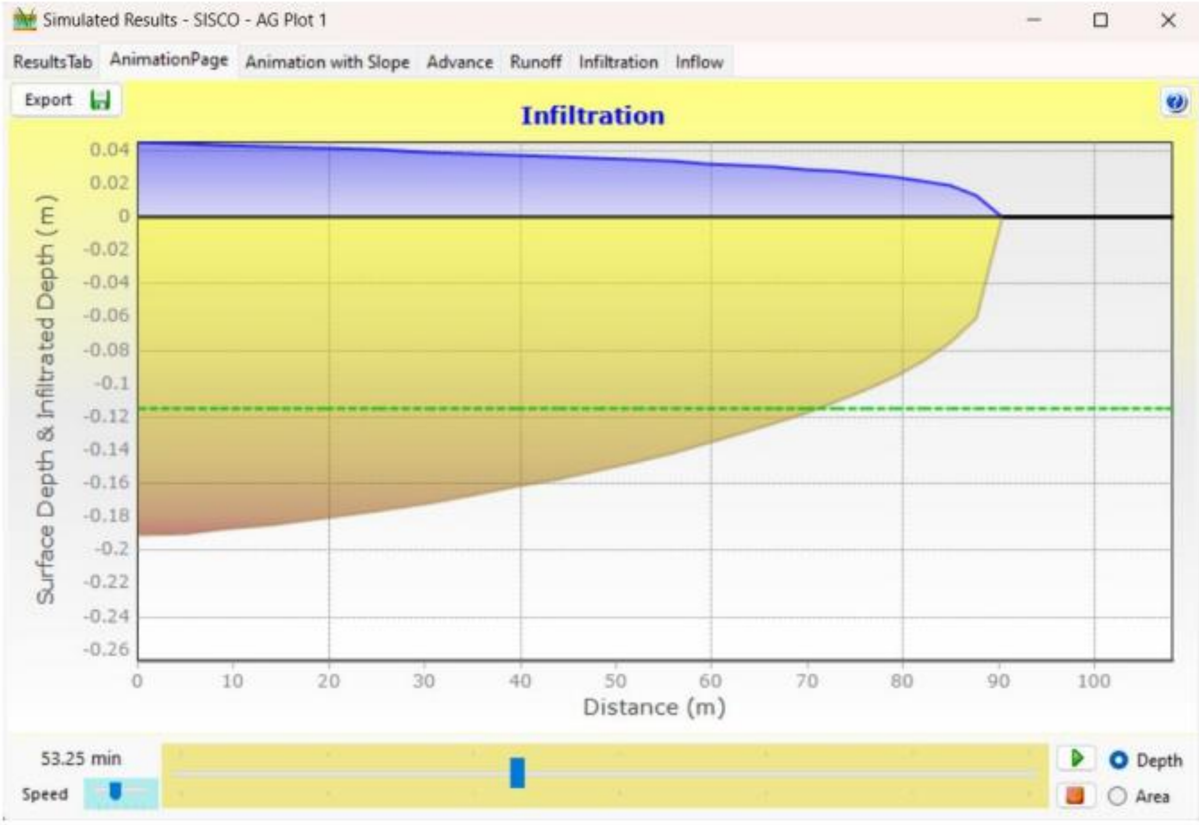


Figure 4.22 Example of SISCO infiltration rate over the furrow distance and time from prior research.

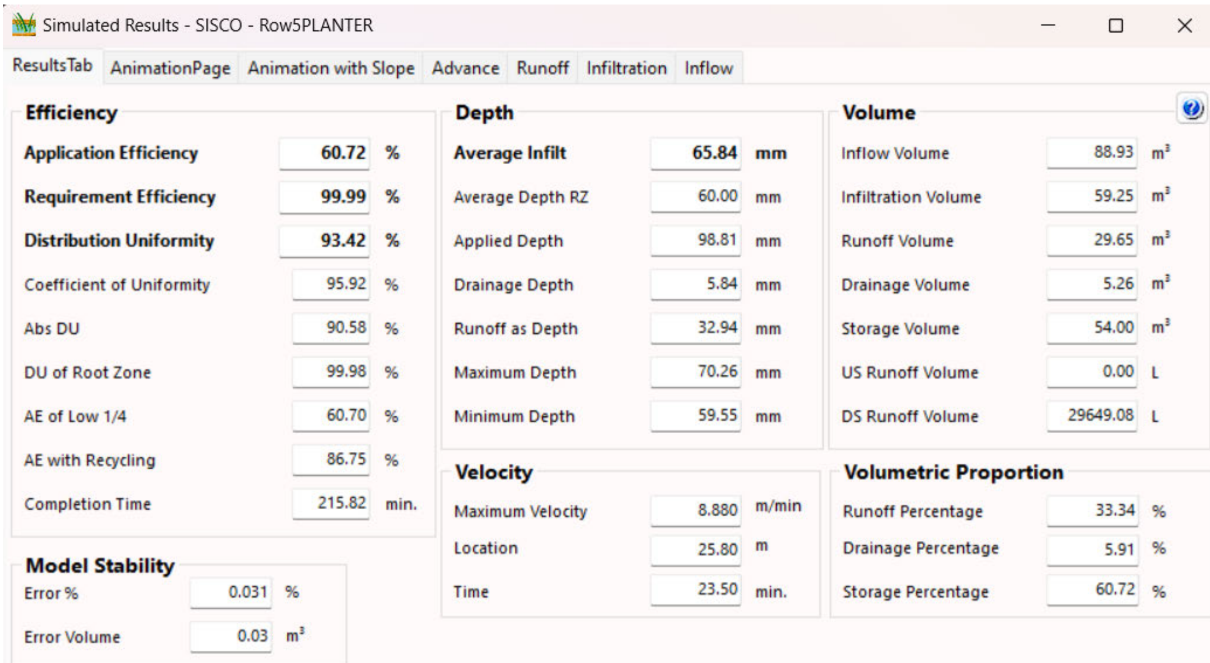
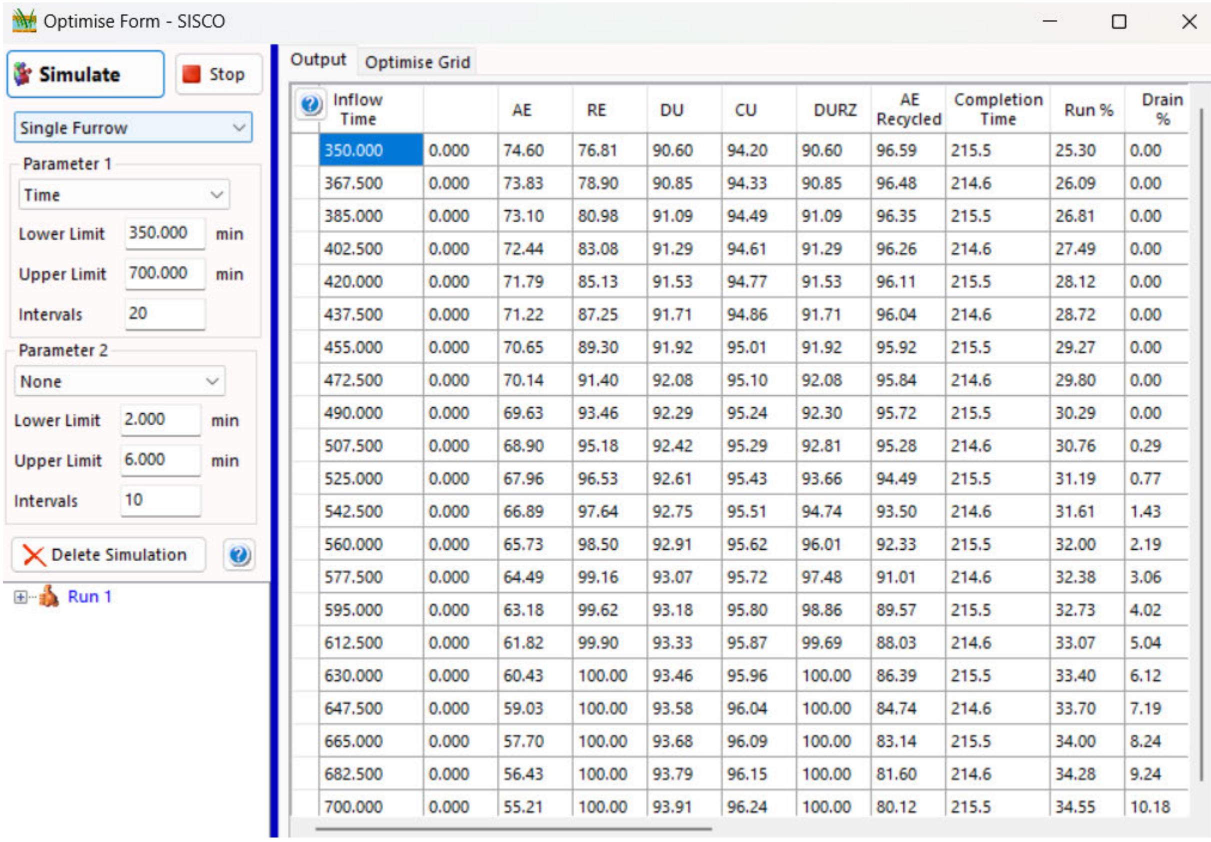


Figure 4.23 Example of SISCO results screen after the simulating of the irrigation event.

The last aspect that will be utilised in chapter 7 of the report is the optimisation feature. Figure 4.24 shows a feature that is not generally available, in which it allows for simulating potential future irrigation events. It can be used for 2 parameters simultaneously which may include changes to the time, flow rate, field length and slope. This feature has not been researched as thoroughly but has great potential to inform farmers of how they can improve their irrigation efficiency.



Inflow Time		AE	RE	DU	CU	DURZ	AE Recycled	Completion Time	Run %	Drain %
350.000	0.000	74.60	76.81	90.60	94.20	90.60	96.59	215.5	25.30	0.00
367.500	0.000	73.83	78.90	90.85	94.33	90.85	96.48	214.6	26.09	0.00
385.000	0.000	73.10	80.98	91.09	94.49	91.09	96.35	215.5	26.81	0.00
402.500	0.000	72.44	83.08	91.29	94.61	91.29	96.26	214.6	27.49	0.00
420.000	0.000	71.79	85.13	91.53	94.77	91.53	96.11	215.5	28.12	0.00
437.500	0.000	71.22	87.25	91.71	94.86	91.71	96.04	214.6	28.72	0.00
455.000	0.000	70.65	89.30	91.92	95.01	91.92	95.92	215.5	29.27	0.00
472.500	0.000	70.14	91.40	92.08	95.10	92.08	95.84	214.6	29.80	0.00
490.000	0.000	69.63	93.46	92.29	95.24	92.30	95.72	215.5	30.29	0.00
507.500	0.000	68.90	95.18	92.42	95.29	92.81	95.28	214.6	30.76	0.29
525.000	0.000	67.96	96.53	92.61	95.43	93.66	94.49	215.5	31.19	0.77
542.500	0.000	66.89	97.64	92.75	95.51	94.74	93.50	214.6	31.61	1.43
560.000	0.000	65.73	98.50	92.91	95.62	96.01	92.33	215.5	32.00	2.19
577.500	0.000	64.49	99.16	93.07	95.72	97.48	91.01	214.6	32.38	3.06
595.000	0.000	63.18	99.62	93.18	95.80	98.86	89.57	215.5	32.73	4.02
612.500	0.000	61.82	99.90	93.33	95.87	99.69	88.03	214.6	33.07	5.04
630.000	0.000	60.43	100.00	93.46	95.96	100.00	86.39	215.5	33.40	6.12
647.500	0.000	59.03	100.00	93.58	96.04	100.00	84.74	214.6	33.70	7.19
665.000	0.000	57.70	100.00	93.68	96.09	100.00	83.14	215.5	34.00	8.24
682.500	0.000	56.43	100.00	93.79	96.15	100.00	81.60	214.6	34.28	9.24
700.000	0.000	55.21	100.00	93.91	96.24	100.00	80.12	215.5	34.55	10.18

Figure 4.24 Example of SISCO optimisation feature that can be used for single and multiple furrow optimising.

4.9 RISK ASSESSMENT

The risk assessment for this particular project will cover the entire methodology and sensor development. The risk assessment is derived from the CAE (Centre for Agricultural Engineering) project 1008258, completed by Simon Kelderman based on CRDC funded

Technology and Integration Project from 2022 to 2025. This risk assessment covers a wide range of different irrigation research and development projects to be conducted throughout this project. The full version of the risk assessment is found in Appendix D.

Risk Assessment Ref No: 6166

'Isaac Halling Dissertation Project'

4.10 CONCLUSION OF METHODOLOGY

The methodology has a crucial role in the overall accuracy of results and data collected for the next processing of results and findings. For this particular irrigation event there was no optimisation strategy adopted by Struanville Farming Co. Through general conversations with the farm manager, it was found that their irrigation practice for fields of approximately 450 metres in length involves a rotation of approximately 12 hours. This is a widespread blanket approach where all furrows across the length of the field are provided with a very similar watering schedule despite the actual moisture level of the soil. The farming management decide based upon their own unique experiences as to when the soil appears to lack in moisture and ultimately when they are going to irrigate. This is a relatively common approach in regard to surface irrigation systems throughout Australia given that the utilisation of instruments to measure flow rate and advance data for SISCO analysis is not yet commercially adopted. This research methodology is aimed at recording the crucial data so that the variability between tramline, normal and planting furrows can be assessed and quantified. The result of this data will allow for recommendations to be made that can reduce both labour requirements and also improve efficiency in terms of water usage.

CHAPTER 5 FIELD TRIAL DATA

5.1 INTRODUCTION

The chapter presents the data collected from the field trial utilising the methodology that was discussed previously in chapter 4. There is an analysis of the Struanville Farming Co soil tests with a series of quantitative data required for modelling of the irrigation event through SISCO. Specifically, the data presented includes the furrow dimensions, field slope, flow rate and advance wave. This information is presented in tables with the raw values that were observed from out in the field. There is also a general discussion about the visual results that were observed whilst out in the field supervising the irrigation event. Overall, the section is an overview of the values that will be utilised in the SISCO modelling process and provides background information to the location that the trial took place.

5.2 SOIL TESTING AND FARMING PRACTICES

As mentioned throughout the methodology soil characteristics play a crucial role in the application efficiency of irrigation. The measurable physical, chemical and biological properties spatially and can change rapidly in response to management (Australian Government, 2021). This is a foremost reason that irrigation research must be informed by soil testing conducted in the field. The results of soil testing within the measured field are found in Appendix C. Testing was performed down to the depth of 90 centimetres by Nutrien Ag Solutions. This data remains relatively accurate given that it was completed in March of 2024. Whilst the entire soil report mainly focuses on the nutrient requirements for growing crops in this paddock, it outlines many crucial factors that provide background information to the research soil conditions. The full results also provide an outline as to the GPS position that the tests were conducted at. A main factor is that the soil texture is defined as primary medium clay which was further categorised as a black vertosol soil type. This information is supported by research that reveals the Darling Downs region where the farm is located is dominated by vertosol soils (Queensland Government, 2011). This is exemplified in figure 5.1.1 below illustrating where the heavy black soils are located, with the trial farm located just southwest from the town of Bowenville.

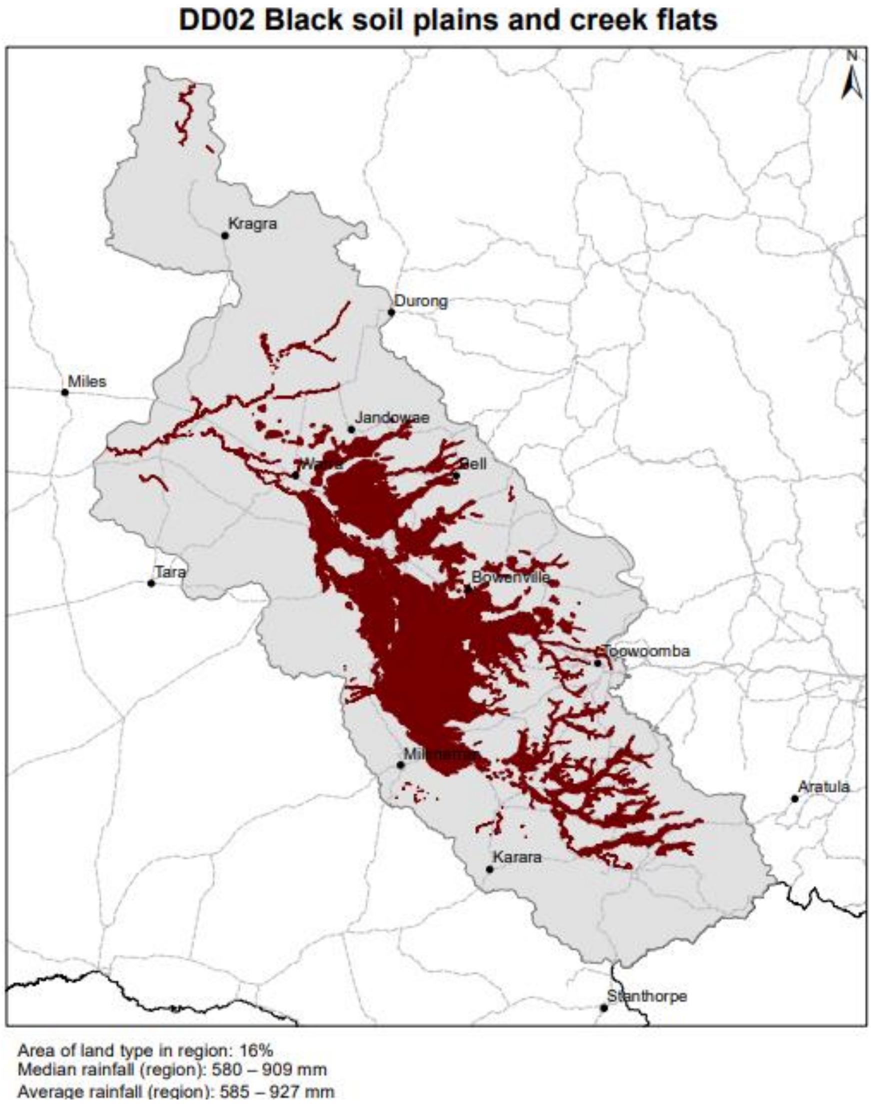


Figure 5.1 Darling Downs soil index report provided by the Queensland Government (2011).

These vertosol soils are often referred to as cracking soil, consist primarily of clay which is known is to exhibit shrinking and swelling properties. This ultimately means that the soil will be prone to cracking when the soil is dry and swells significantly when saturated. Figure 5.2 below is an image taken from the field soil analysis, where it is observed that the dry soil has revealed significantly cracking. This clay soil is beneficial for the moisture retention and self-mulching properties however due to the size of the clay particles can be prone to compaction. Compaction on farms remains a key factor, impacting on factors of root movement, air circulation, nutrient uptake, drainage and most important for this research infiltration. Visual inspections from the field and communications with the farm management team reveals the adoption of Controlled Traffic Farming (CTF) practices. This means that the farm has permanent wheel tracks that the farming equipment travels down. Whilst this method means a significant amount of compaction along the wheel track/tramline furrows it allows the rest of the field to be left relatively unaffected. It was revealed that the farm uses a planter that is 8m in width and a self-propelled boom sprayer covering 24 metres. This meant that the major tramline compaction would be occurring where the planting tracks and spraying tracks would line up every 24 metres. For the exact placement of sensors in the specific furrows, a diagram is shown back in figure 4.3. The results from this research will quantify the effect of compaction on the irrigation performance.

Figure 5.2 Plot of the field slope survey data of reduced level over the furrow length.

5.3 FURROW DIMENSIONS

As referenced in the previous chapter, furrow dimensions are required for the SISCO software to process the data. It was also previously mentioned that the furrow dimensions have minimum impact on the results however it still remains a factor that has been measured in this project. The results taken from the field are outlined in the below tables, with a singular measurement taken to represent each of the tramline, normal and planter furrows. Table 5.1 demonstrates that dimensions of the tramline furrow which are heavily compacted with it noticed that they are relatively wide at the top width measurement. This could potentially be a result of the machinery wheel tracks causing the furrow to be widened. It is also seen in table 5.3 which shows the furrow dimensions for the planting tracks with reasonably similar values to the tramlines. There are a few differences noted in table 5.2 which illustrates the normal uncompacted furrows with it observed to be narrower but deeper than the other furrows measured. The recording of the furrow dimensions is not exact but reflective of the field given that furrow dimensions could change throughout the length of the furrow. Ultimately the data did reveal enough correlation to denote a specific relationship or trend between the level of compaction of the furrow and the furrow dimensions.

Table 5.1 Measured furrow dimensions for Row 1 and 2 (tramlines).

ROW 1 and 2 (Tramline/Heavy Compaction)	
Component	**Dimensions (mm)**
Top Width	700
Middle Width	450
Bottom Width	300
Max Height	110

Table 5.2 Measured furrow dimensions for Row 3 and 4 (normal/uncompacted).

ROW 3 and 4 (Normal/Uncompacted)	
Component	**Dimensions (mm)**
Top Width	600
Middle Width	450
Bottom Width	275
Max Height	125

Table 5.3 Measured furrow dimensions for Row 5 and 6 (planting tracks).

ROW 5 and 6 (Planting Tracks)	
Component	**Dimensions (mm)**
Top Width	700
Middle Width	600
Bottom Width	300
Max Height	100

The reference for how these values were determined is found back in the methodology chapter particularly referring to figure 4.6. It outlines that SISCO software requires the general dimensional shape of the furrow. This consists of the top width, middle width, bottom width and finally the max height. Ultimately these values will have a very small effect on the SISCO simulation however they are still required and give a background on how the compaction from machinery may influence the shape of the furrow.

5.4 FIELD SLOPE

The field slope data gathered in the field is tabulated below in table 5.4. The data collected has potential for human error given the manual recording of data through a dumpy level and surveying staff. For this intended purpose data was collected at many points along the furrow however the most important part was the starting and end height to calculate an average slope value. With reference to the plotted data in figure 5.3 there appears to be a generally uniform slope down the field. This was only conducted for one of the furrows in the paddock and it was assumed that the rest of the testing furrows would yield the same of extremely similar results.

Table 5.4 Recorded height and reduced level (RL) measurements recorded from base of a single furrow for determining slope.

Approx Distance Along Furrow (m)	Recorded Height (mm)	Reduced Level, RL (mm)
0*	1270	0
18	1310	-0.04
36	1370	-0.1
54	1380	-0.11
72	1410	-0.14
90	1450	-0.18
108	1450	-0.18
126	1460	-0.19
144	1500	-0.23
162	1505	-0.235
180	1540	-0.27
198	1565	-0.295
216	1580	-0.31
234	1616	-0.346
252	1629	-0.359
270	1649	-0.379
288	1680	-0.41
306	1693	-0.423
324	1720	-0.45
342	1765	-0.495
360	1780	-0.51
378	1800	-0.53
396	1790	-0.52
414	1820	-0.55
432	1840	-0.57
450	1870	-0.6

* The start of the row was used as the Datum Point for calculating the reduced level (RL).

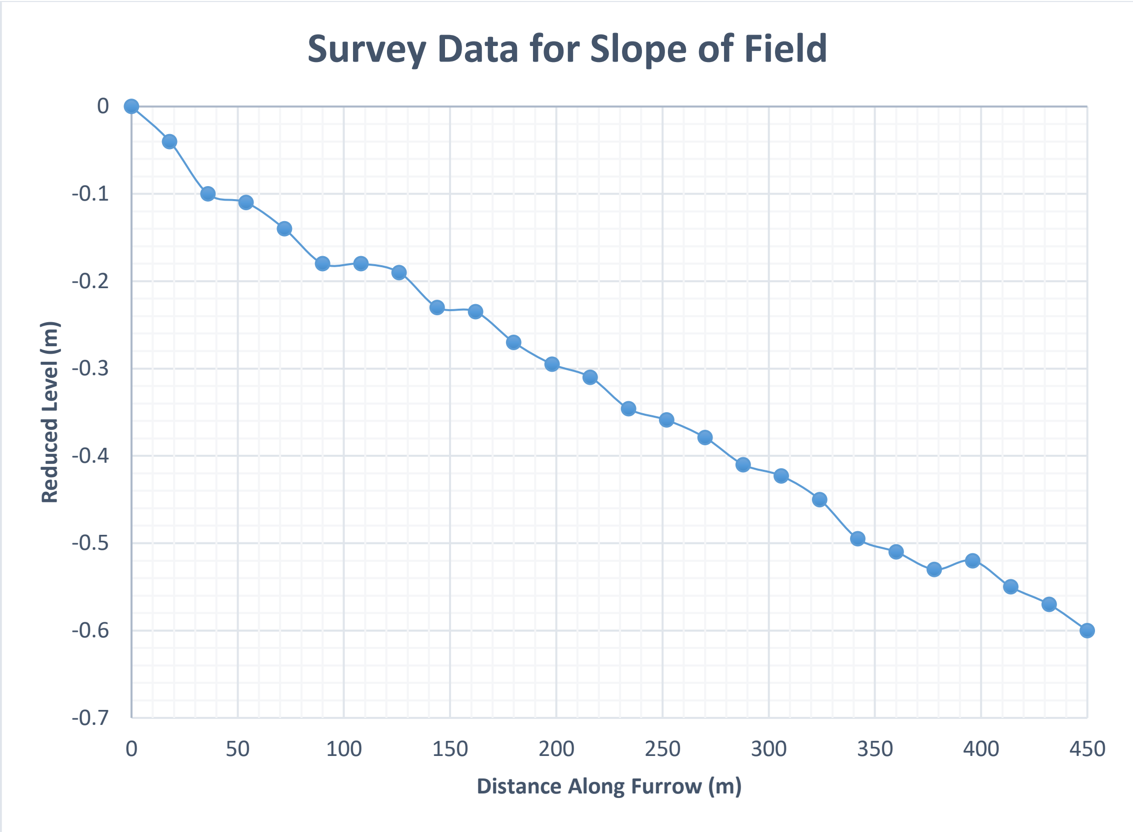


Figure 5.3 Plot of the field slope survey data of reduced level over the furrow length.

Utilising the height measurement at the start and end of the furrow an average slope value can be determined. The exemplar calculation is conducted below. The final value of 0.00133 was used in the SISCO simulations with the slope value kept as a constant across the six furrows under analysis. Overall, the slope data recorded is as expected from previous reviewing of literature and experience in surface irrigation systems.

$$RL_{0m} = 0m$$

$$RL_{450m} = 0.6m$$

$$Slope = \frac{(RL_{450m} - RL_{0m})}{(End\ Distance - Start\ Distance)}$$

$$Slope = \frac{0.6}{450} \approx 0.00133$$

5.5 HYDRAULIC HEAD AND FLOW RATE

As outlined throughout the methodology and prior literature the flow rate remains a crucial aspect in the overall performance of an irrigation event. It is therefore important that the results collected are reflective of the field trial event particularly to ensure greater accuracy when simulating the event in the SISCO software. The six tables below show the measurements in hydraulic head from the instrument explained in the methodology. The time of these head measurements were recorded specific to the nearest minute and was outlined throughout the tables. From the hydraulic head measurements, the flowrate was calculated for that particular point in time. On a general note, the tables exhibit very similar values however there were minor differences that may have been a result of slight variations in the siphon hoses or the positioning along the head ditch.

Table 5.5 Hydraulic head and flow rate of row 1 (tramline) over duration of irrigation event.

ROW 1 (Tramline/Heavy Compaction)			
Duration of Event (mins)	**Time of Measurement (hr:min)**	**Hydraulic Head (mm)**	**Calculated Flowrate (L/s)**
0	6:30:00 AM	216	2.75436
215	10:05:00 AM	216	2.75436
225	10:15:00 AM	200	2.63391
235	10:25:00 AM	184	2.51346
245	10:35:00 AM	168	2.39301
255	10:45:00 AM	152	2.27256
265	10:55:00 AM	136	2.15211
275	11:05:00 AM	120	2.03167
286	11:16:00 AM	104	1.91122
630	5:00:00 PM	104	1.91122

Table 5.6 Hydraulic head and flow rate of row 2 (tramline) over duration of irrigation event.

ROW 2 (Tramline/Heavy Compaction)			
Duration of Event (mins)	**Time of Measurement (hr:min)**	**Hydraulic Head (mm)**	**Calculated Flowrate (L/s)**
0	6:31:00 AM	229.00	2.83603
215	10:06:00 AM	229.00	2.83603
225	10:16:00 AM	211.86	2.71040
235	10:26:00 AM	194.71	2.58477
245	10:36:00 AM	177.57	2.45914
255	10:46:00 AM	160.43	2.33351
265	10:56:00 AM	143.29	2.20788
275	11:06:00 AM	126.14	2.08225
282	11:13:00 AM	109.00	1.95662
629	5:00:00 PM	109.00	1.95662

Table 5.7 Hydraulic head and flow rate of row 3 (normal) over duration of irrigation event.

ROW 3 (Normal/Uncompacted)			
Duration of Event (mins)	**Time of Measurement (hr:min)**	**Hydraulic Head (mm)**	**Calculated Flowrate (L/s)**
0	6:34:00 AM	214.00	2.74158
219	10:13:00 AM	214.00	2.74158
229	10:23:00 AM	197.43	2.61496
239	10:33:00 AM	180.86	2.48834
249	10:43:00 AM	164.29	2.36173
259	10:53:00 AM	147.71	2.23511
269	11:03:00 AM	131.14	2.10850
279	11:13:00 AM	114.57	1.98188
285	11:19:00 AM	98.00	1.85527
626	5:00:00 PM	98.00	1.85527

Table 5.8 Hydraulic head and flow rate of row 4 (normal) over duration of irrigation event.

ROW 4 (Normal/Uncompacted)			
Duration of Event (mins)	**Time of Measurement (hr:min)**	**Hydraulic Head (mm)**	**Calculated Flowrate (L/s)**
0	6:33:00 AM	245.00	2.93343
202	9:55:00 AM	245.00	2.93343
212	10:05:00 AM	231.22	2.83655
222	10:15:00 AM	217.44	2.73967
232	10:25:00 AM	203.67	2.64279
242	10:35:00 AM	189.89	2.54591
252	10:45:00 AM	176.11	2.44903
262	10:55:00 AM	162.33	2.35215
272	11:05:00 AM	148.56	2.25527
282	11:15:00 AM	134.78	2.15839
289	11:22:00 AM	121.00	2.06151
627	5:00:00 PM	121.00	2.06151

Table 5.9 Hydraulic head and flow rate of row 5 (planting tracks) over duration of irrigation event.

ROW 5 (Planting Tracks)			
Duration of Event (mins)	**Time of Measurement (hr:min)**	**Hydraulic Head (mm)**	**Calculated Flowrate (L/s)**
0	6:34:00 AM	240.00	2.90335
205	9:59:00 AM	240.00	2.90335
215	10:09:00 AM	226.11	2.80406
225	10:19:00 AM	212.22	2.70477
235	10:29:00 AM	198.33	2.60548
245	10:39:00 AM	184.44	2.50619
255	10:49:00 AM	170.56	2.40690
265	10:59:00 AM	156.67	2.30762
275	11:09:00 AM	142.78	2.20833
285	11:19:00 AM	128.89	2.10904
292	11:26:00 AM	115.00	2.00975
626	5:00:00 PM	115.00	2.00975

Table 5.10 Hydraulic head and flow rate of row 6 (planting tracks) over duration of irrigation event.

ROW 6 (Planting Tracks)			
Duration of Event (mins)	**Time of Measurement (hr:min)**	**Hydraulic Head (mm)**	**Calculated Flowrate (L/s)**
0	6:28:00 AM	231.00	2.84839
215	10:03:00 AM	231.00	2.84839
225	10:13:00 AM	215.63	2.73579
235	10:23:00 AM	200.25	2.62320
245	10:33:00 AM	184.88	2.51060
255	10:43:00 AM	169.50	2.39801
265	10:53:00 AM	154.13	2.28541
275	11:03:00 AM	138.75	2.17282
285	11:13:00 AM	123.38	2.06022
297	11:25:00 AM	108.00	1.94762
632	5:00:00 PM	108.00	1.94762

The data for the measured flow rates for each of the six furrows throughout the tables above was plotted in figure 5.4 graph. This provides a graphical comparison to identify any data discrepancies and compare the flow rate for each of the furrows. As mentioned, it appears that there is no major differences between any of the flowrates with approximately 0.3 L/s the maximum observed difference at any one point. One of the interesting aspects observed in the results and whilst completing the tests was a significant reduction in the flowrate around 225 minutes through the irrigation event. It was believed to be caused by the starting of more furrow further up along the head ditch which caused the level of water in this supply channel to drop and ultimately a reduced flow rate from this point on. It was assumed that the flow rate dropped off gradually and evenly during this time before it plateaued around 280 minutes into the irrigation at approximately 1.9 to 2.0 L/s. There is potential for errors in these exhibited results however it does appear to match across the furrows being relatively similar to prior research data and yielding values expected by the farm management.

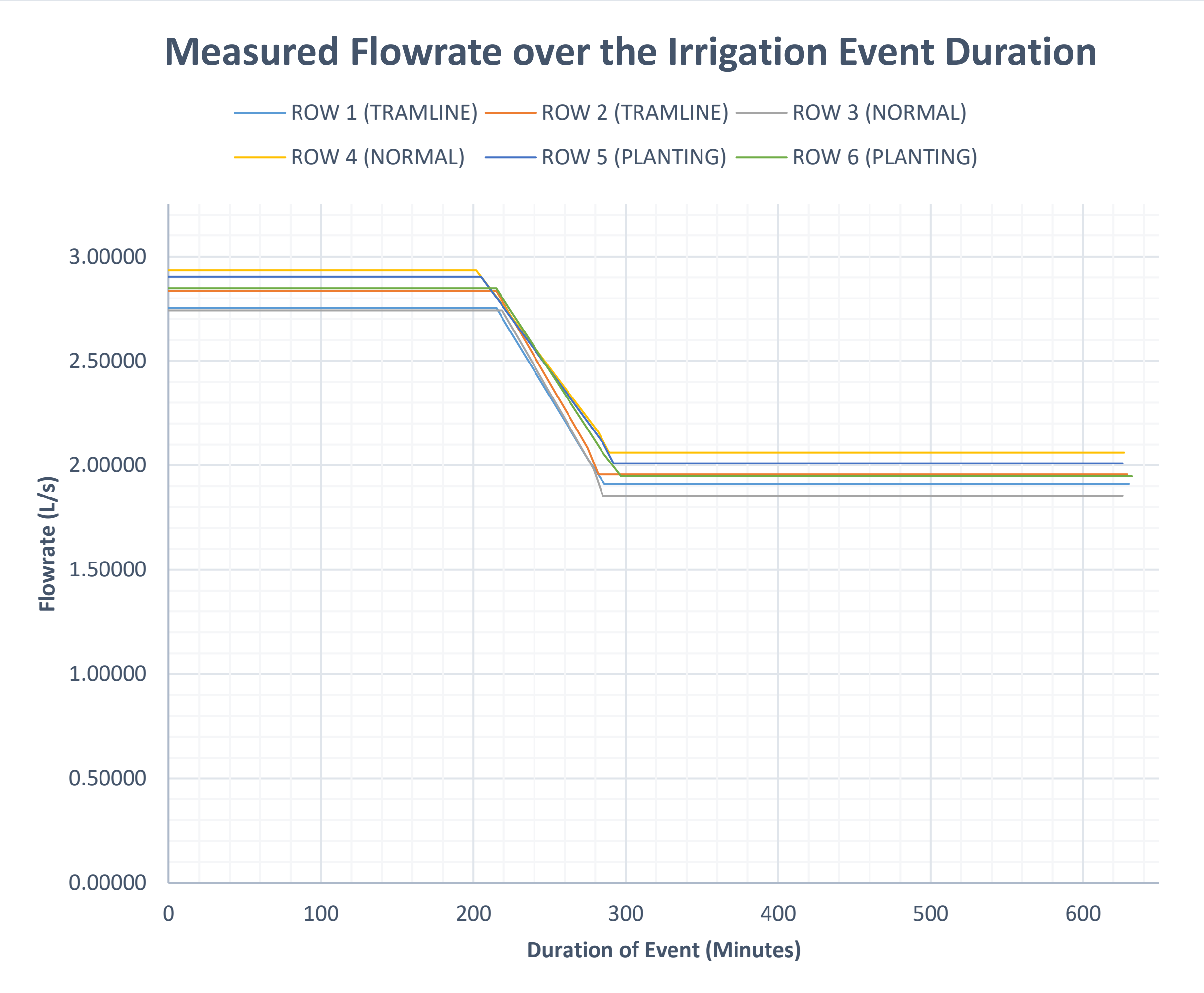


Figure 5.4 Graphical comparison of the measure flowrate for each row over the duration of the irrigation event.

5.6 ADVANCE DATA

The advance data is one of the most important aspects for the simulation of the results to occur on the SISCO software. As mentioned in the methodology a series of 35 advance sensors were spread across 6 furrows with two in each of the tramlines, normal and planting furrows. Due to an unknown error in some of the sensors data was only recorded from a total of 33 sensors with two sensors not transmitting any data. Particularly the sensor that was placed 82.11m along row 2 and the sensor at 402.57m in row 3 did not transmit any data. Row 6 did not have a sensor placed at 402.57m did not due to only 35 sensors being available for the trial. This is believed to have minimal effect; despite this discrepancy the rest of the collected data is enough for SISCO to produce an accurate simulation of the irrigation event. The below six tables are the recorded timestamps that each individual sensor was triggered as a result of the advance wave/water reaching that point along the furrow. This information can illustrate the effect of the compaction on the movement of water in an irrigation event. Whilst the tables illustrate the raw data from the advance sensors the most valuable information is observed in a comparative graphical representation of figure 5.5

Table 5.11 Recorded advance sensor timestamps of Row 1 (tramline) along furrow over the duration of the event.

ROW 1 (Tramline/Heavy Compaction)		
Exact Distance Along Furrow (m)	**Time of Sensor Trigger (hr:min)**	**Duration of Irrigation Event (mins)**
0	6:30:00 AM	0
82.11	6:54:00 AM	24
153.72	7:17:00 AM	47
237.27	7:45:00 AM	75
319.57	8:13:00 AM	103
402.57	8:43:00 AM	133

Table 5.12 Recorded advance sensor timestamps of Row 2 (tramline) along furrow over the duration of the event.

ROW 2 (Tramline/Heavy Compaction)		
Exact Distance Along Furrow (m)	**Time of Sensor Trigger (hr:min)**	**Duration of Irrigation Event (mins)**
0	6:31:00 AM	0
82.11	-	-
153.72	7:17:00 AM	47
237.27	7:43:00 AM	73
319.57	8:10:00 AM	100
402.57	8:36:00 AM	126

Table 5.13 Recorded advance sensor timestamps of Row 3 (normal) along furrow over the duration of the event.

ROW 3 (Normal/Uncompacted)		
Exact Distance Along Furrow (m)	**Time of Sensor Trigger (hr:min)**	**Duration of Irrigation Event (mins)**
0	6:34:00 AM	0
82.11	7:09:00 AM	39
153.72	7:55:00 AM	85
237.27	9:04:00 AM	154
319.57	10:42:00 AM	252
402.57	-	-

Table 5.14 Recorded advance sensor timestamps of Row 4 (normal) along furrow over the duration of the event.

ROW 4 (Normal/Uncompacted)		
Exact Distance Along Furrow (m)	**Time of Sensor Trigger (hr:min)**	**Duration of Irrigation Event (mins)**
0	6:33:00 AM	0
82.11	7:08:00 AM	38
153.72	7:49:00 AM	79
237.27	8:51:00 AM	141
319.57	10:12:00 AM	222
402.57	1:36:00 PM	426

Table 5.15 Recorded advance sensor timestamps of Row 5 (planting tracks) along furrow over the duration of the event.

ROW 5 (Planting Tracks)		
Exact Distance Along Furrow (m)	**Time of Sensor Trigger (hr:min)**	**Duration of Irrigation Event (mins)**
0	6:34:00 AM	0
82.11	7:04:00 AM	34
153.72	7:33:00 AM	63
237.27	8:10:00 AM	100
319.57	8:52:00 AM	142
402.57	9:38:00 AM	188

Table 5.16 Recorded advance sensor timestamps of Row 6 (planting tracks) along furrow over the duration of the event.

ROW 6 (Planting Tracks)		
Exact Distance Along Furrow (m)	**Time of Sensor Trigger (hr:min)**	**Duration of Irrigation Event (mins)**
0	6:28:00 AM	0
82.11	7:09:00 AM	39
153.72	7:38:00 AM	68
237.27	8:13:00 AM	103
319.57	8:53:00 AM	143
402.57	-	-

Figure 5.5 below is a graphical presentation of the raw data that is observed in tables 5.11 to 5.16 above. This allows to visualise the data and observe any relationships or trends that reveal themselves. The testing was completed across 2 of each furrows to improve the accuracy of the data and reveal if there is an outlier or anomaly. As illustrated in the graph the tramline and planter furrows in particular exhibit extremely similar advance wave movements which suggests the data is representative of the field. This ultimately means that

it can be assumed the tramlines across the width of the field are expected to record relatively similar results with the same flowrate. The normal or uncompacted furrows are not as closely linked as the other tested parameters; however, the shape of the curve is similar to a point which can conclude that there was no discrepancies or anomaly across the furrows that were studied.

With reference to graph, it appears that tramline data observed in row 1 and 2 is the fastest moving furrow with water reaching the end (450m) in approximately 150 minutes. This is representative of prior research which suggests that compacted soil can cause water to flow more freely. It is also therefore expected that the planting tracks would be slower than the tramline but given they still experience some compaction, they would reach the end quicker than the uncompacted tests. This is exemplified in the data where it takes approximately 220 minutes for both planting track furrows to reach the end. As expected, the uncompacted or normal furrows tested both were significantly slower with less compaction resulting in a slower movement of water. Specifically for row 3 it took a projected full 660 minutes to actually reach the field tail drain. Row 4 was even further behind with data suggesting that the water only reached 430 metres down the field over the 660 minute duration of the irrigation. It is important that this raw data does not recognise any new conclusions but further supports that there is a relationship between the level of compaction and the movement of water down the length of a furrow. This information collected can further be processed in the SISCO software to evaluate the performance of each individual row and ultimately deduce conclusions to improve the efficiency of the entire irrigation operation.

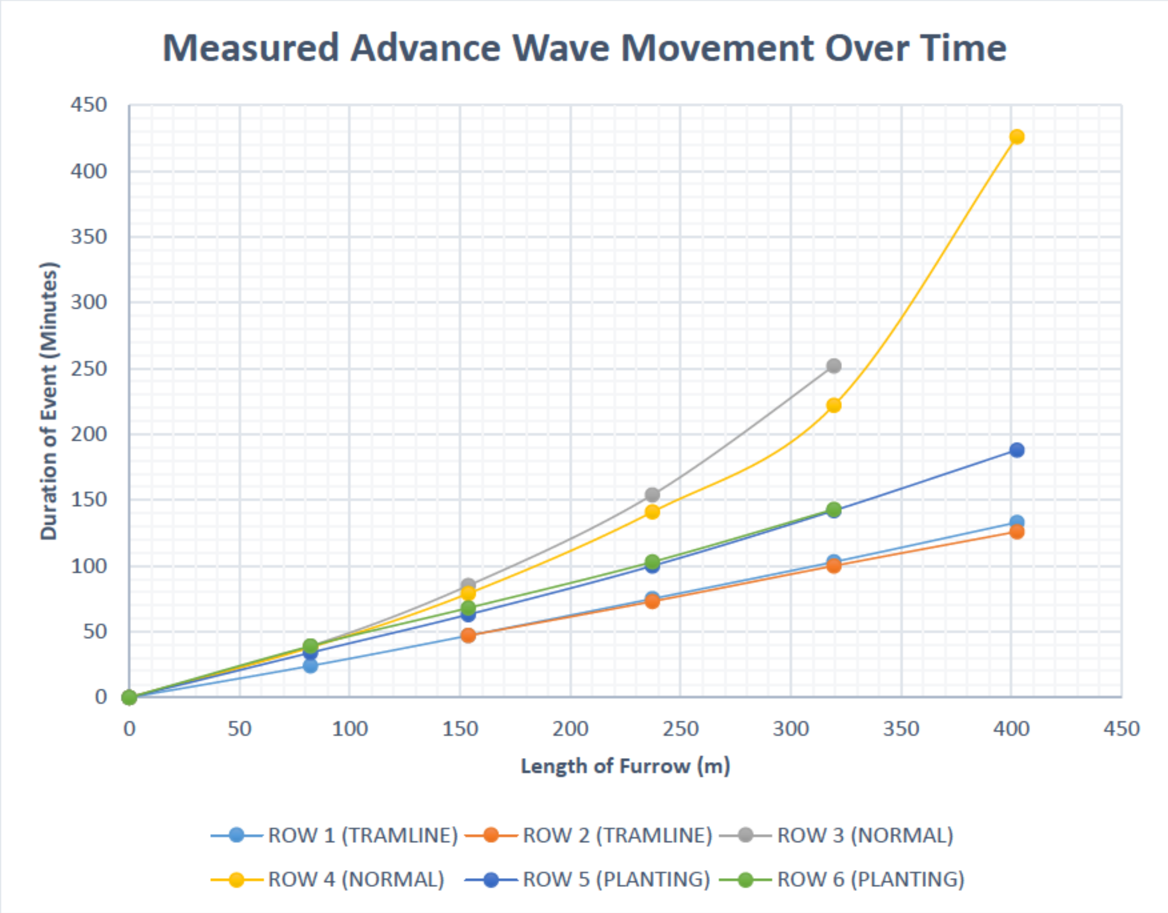


Figure 5.5 Graphical comparison of the measured advance wave movement down the furrow over duration of the irrigation event.

5.7 VISUAL RESULTS

Whilst there was many different measuring and recording instruments utilised throughout the duration of the experiment, through supervising the irrigation event there were some notable physical differences across the 6 different furrows. The first prominent aspect noticed from the field trial was that the advance wave for row 3 and 4 was significantly less in comparison to the other tramlines and planting tracks. Figure 5.6 provides visual depiction of this occurring which correlates directly to the recorded times from the advance moisture sensors in the prior section of the report.

Figure 5.6 Image of water moving down the furrow from field trial of Row 3 and 4 (normal).

Although it was expected that there would be a visual difference between the furrows, there was also a visual difference between the water infiltration particularly in the lateral direction. Images were taken in figure 5.7, 5.8 and 5.9 illustrating the lateral moisture movement through the soil towards the corn for each of the different furrows examined. The photos were taken at approximately 50 m down the length of the furrow after approximately 300 minutes of irrigation. With specific reference to figure 5.7, the tramlines of row 1 and 2 appear to have a line of moisture that only just overlaps the corn row. This is different when compared to figure 5.8 which shows the normal or uncompacted rows of 3 and 4. It depicts more lateral water movement past the corn. Figure 5.9 illustrates the planting tracks of row

5 and 6, with the image showing similar lateral infiltration to the tramlines. It does seem to have a slight increase in the lateral movement however not much in comparison to the uncompacted data. Whilst there are many extra factors that can influence the lateral movement of water including furrow dimensions, it is interesting to note an increase in the appearance of lateral movement for the uncompacted trial. This denotes from a visual perspective that the reduced level of compaction increases the amount of lateral water movement.

Figure 5.7 Photo illustrating the lateral moisture movement towards the corn plant for row 1 and 2 (tramlines).

Figure 5.8 Photo illustrating the lateral moisture movement towards the corn plant for row 3 and 4 (normal).

Figure 5.9 Photo illustrating the lateral moisture movement towards the corn plant for row 5 and 6 (tramlines).

5.8 CONCLUSION OF RAW DATA

The project has required the collection of many different measurements each with a given research purpose. The slope, advance, furrow dimensions and inflow data are crucial elements for the SISCO modelling to occur in the next chapter. There is also a series of background soil testing to establish context as to location that the project takes place and a series of visual results. There were some unexpected results in the form of the inflow rate dropping mid-way through the irrigation event. Whilst this is not an ideal situation, the flow rate was still comprehensively measured to determine what the change in head meant for the flow rate. Finally, there were some problems with some of the sensors that caused data not to be collected at particular stages throughout the irrigation event. This only occurred in 2 of the sensors fortunately ensuring that there is still at least 5 advance measurements for utilisation in SISCO. It is unsure if this potential sensor fault was related to a construction error or another unknown reason that it could not transmit the data. A future project may include investigating the reliability of the sensors and examining the possible reasons for the sensors to not work. Overall sufficient raw data was collected from the field that can be used in the evaluation and optimisation processes.

CHAPTER 6 SISCO DATA MODELLING

6.1 SISCO INTRODUCTION

With the collection of all the important raw data, SISCO software was utilised to simulate the irrigation event for each individual furrow in accordance with the recorded data. SISCO has the potential to model the data and recognise key characteristics that dictate the overall efficiency and effectiveness of the irrigation. The most important results processed through SISCO include the advance and recession, amount of runoff, infiltration and efficiency of the application. Whilst there are many different aspects that can be altered in the SISCO software, this project assumed the following to be constant across all simulations:

- The soil has a soil moisture deficiency and quantity of water required for the corn crop is 60mm.
- The recycling efficiency of the irrigation water is 90%.
- The cut off time was kept at 5:00pm sharp across all tests.
- Mannings n Value is 0.03 for black vertosol soils.

The first aspect of the soil moisture deficiency is derived from information about the corn plants plant available water capacity (PAWC). Bayer Crop Science group found a corn crop in the relatively early vegetative stage has an assumed maximum root depth reach of approximately 61 centimetres (2022). They also suggest clay dominant soil has a water storage capacity of approximately 50mm to 64mm per 30cm. Applying this storage capacity over the 61cm root zone, it can be determined that the plant available water capacity at this stage in the plants development is around 102mm to 130mm. Whilst this value suggests the maximum plant available water it does not account for the refill point or maximum allowable depletion (MAD) for the crop. It was recommended by Bayer that corn has a MAD of 50%

of the PAWC before the plant begins to stress and permanent wilting occurs (2022). Ultimately this led to an assumption of 60mm moisture deficit in order to not reduce the yielding potential of the crop.

Many farmers that practice surface irrigation have the ability to recapture and recycle runoff meaning that a portion of the runoff volume is not considered to be a loss and is available for future irrigation events. In addition to standard efficiency metrics, SISCO also calculates the application efficiency with recycling which adjusts the efficiency taking into account the proportion of runoff that might be expected to be recovered. The recycling efficiency of surface irrigation systems can be extremely difficult to determine and varies from many external factors including evaporation, soil type and length of the tail drain. The final value of 90% was chosen with an assumption that approximately 10% of water that runs off will be lost in some capacity and the remaining 90% is recovered and pumped back into the storage. While the value does not influence crucial factors like the infiltration, it does impact the application efficiency of the irrigation event.

The cutoff time to the pump supplying the channel system was provided by the farm manager. It is assumed that all flow into the furrows stopped at this time. In reality it may take several minutes for the water level in the channel to decline to a point where the flow ceases in individual furrows. This will ultimately have minimal effect on the overall simulation results however may present slight error in the exact time of irrigation duration.

6.2 ROW 1 (TRAMLINE) INDIVIDUAL FURROW ANALYSIS

The first analysis completed in SISCO was completed on row 1 which reflected a tramline furrow which experiences significant compaction from heavy machinery including tractors, sprayers and also from harvesters. The below figures are provided directly from the SISCO simulation displaying the most important results to evaluate the performance of the irrigation. Figure 6.1 below provides an illustration of the measured advance and a calculated recession wave. As expected, the more compacted soil tends to display a faster movement of water down the furrow reaching the end of the field at only 150 minutes into the event. This ultimately led to the results graphed in figure 6.2 which illustrates the amount of runoff from the field. The runoff commences at a high rate before steading to a consistent 1.4 L/s coinciding with the reduction in the inflow. The data suggests that not much of the water is actually infiltrating into the soil after the initial soil intake. SISCO suggests in figure 6.4 that the average infiltration experienced is 37.26mm significantly less than the assumed requirement of 60mm. It is exemplified in figure 6.3 that the infiltration is relatively uniform varying from 36mm to 38mm along the length of the furrow. The data from this individual row 1 analysis suggests that not enough infiltration is occurring in the compacted soil and most water is just flowing through to the tail drain. Thus is the reason for an observed application evaluation of 39.5% and only a requirement efficiency of 62.09%, ultimately meaning that the irrigation is not satisfying plant requirements.

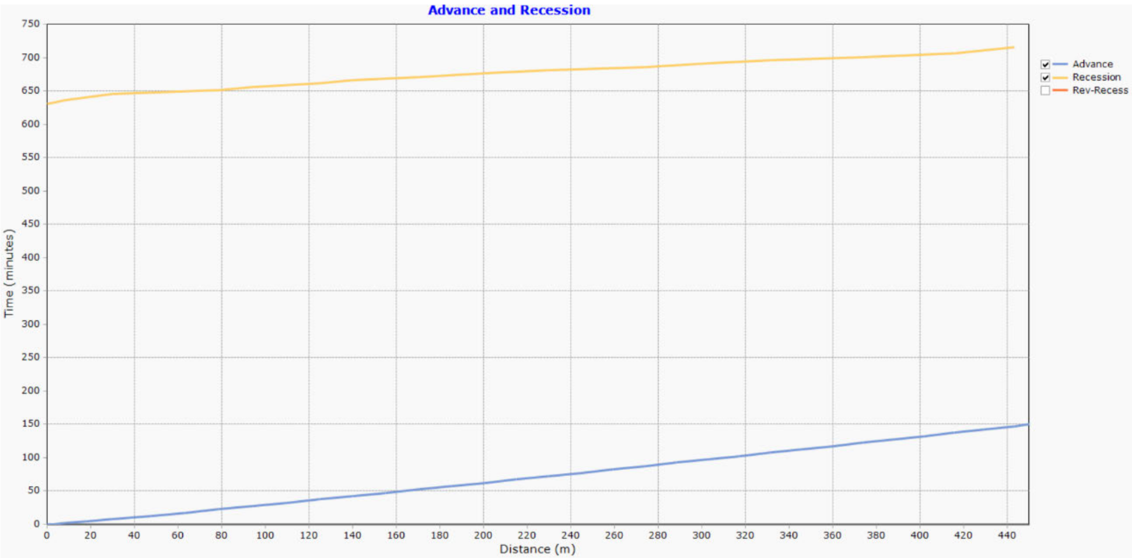


Figure 6.1 Advance and Recession wave plot along the furrow as provided by SISCO software for Row 1 (tramline).

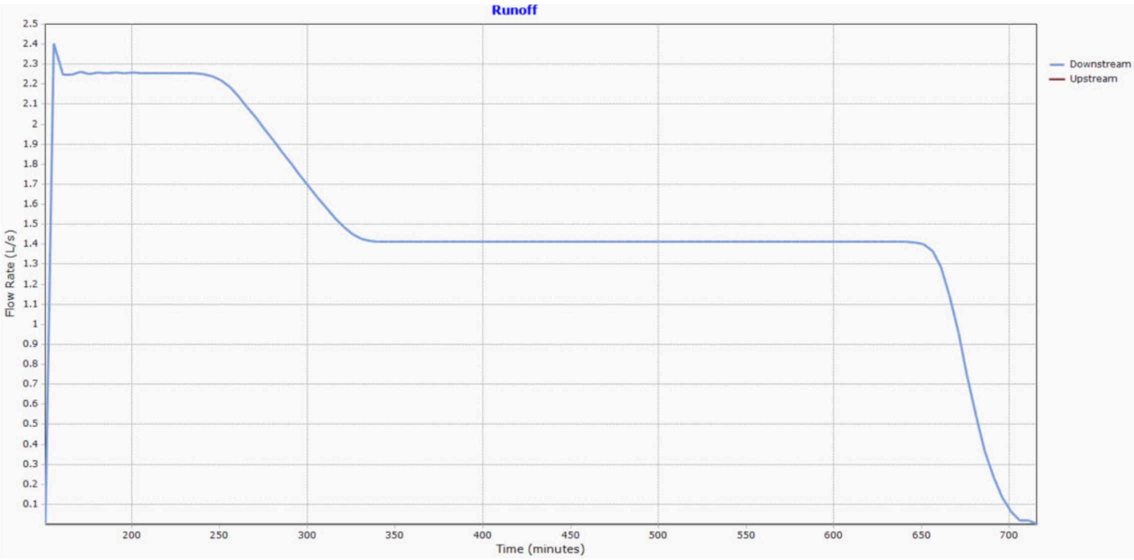


Figure 6.2 Runoff graph over the duration of the event as calculated by SISCO software for Row 1 (tramline).

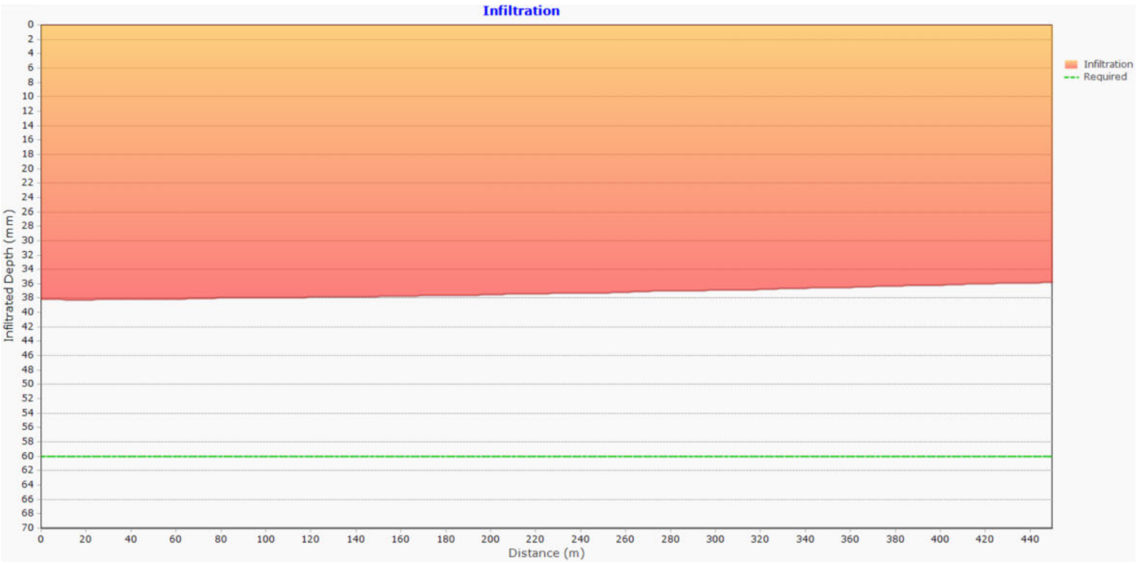


Figure 6.3 Infiltration over the length of the furrow as determined by SISCO software for Row 1 (tramline).

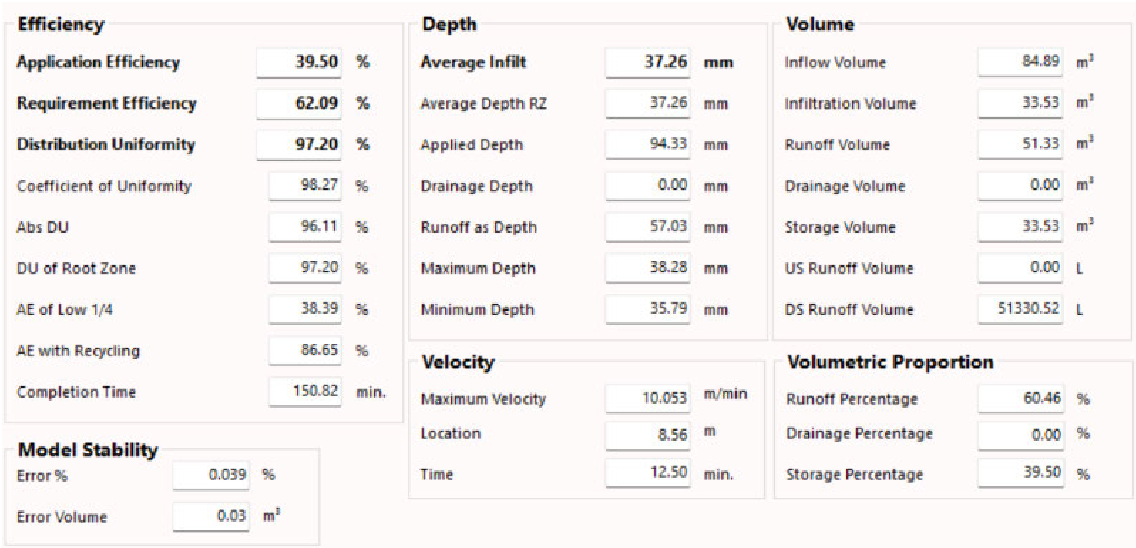


Figure 6.4 Summary of results from SISCO software for Row 1 (tramline) irrigation event.

6.3 ROW 2 (TRAMLINE) INDIVIDUAL FURROW ANALYSIS

Row 2 is also a tramline and heavily compacted furrow that was completed as a control test particularly to validate or disprove that there is a specific relationship between compaction and irrigation performance. The advance data was as measured and interpolated with the water reaching the end in around 145 minutes. Figure 6.6 also displays similar shape data to the first tramline row with a significant proportion of the water running off. It does however appear to have more runoff than row 1 with a plateau at around 1.9 L/s instead of 1.4 L/s. This may have been a difference caused by an increased flow rate in contrast to row 1. This substantial runoff data portrayed in figure 6.6 is a result of the low 20mm of infiltration in the furrow (figure 6.7). With reference to the results summary of SISCO in figure 6.8 the requirement efficiency is 33.05% of what the plant is assumed to require at this stage in its growth. It also reveals an average infiltration of only 19.83mm which is extremely low for the corn crop and the cause for the application efficiency to yield only 20.51%. Ultimately the results share similar characteristics to row 1, with the overall conclusion that there is poor irrigation performance within the compacted furrows.

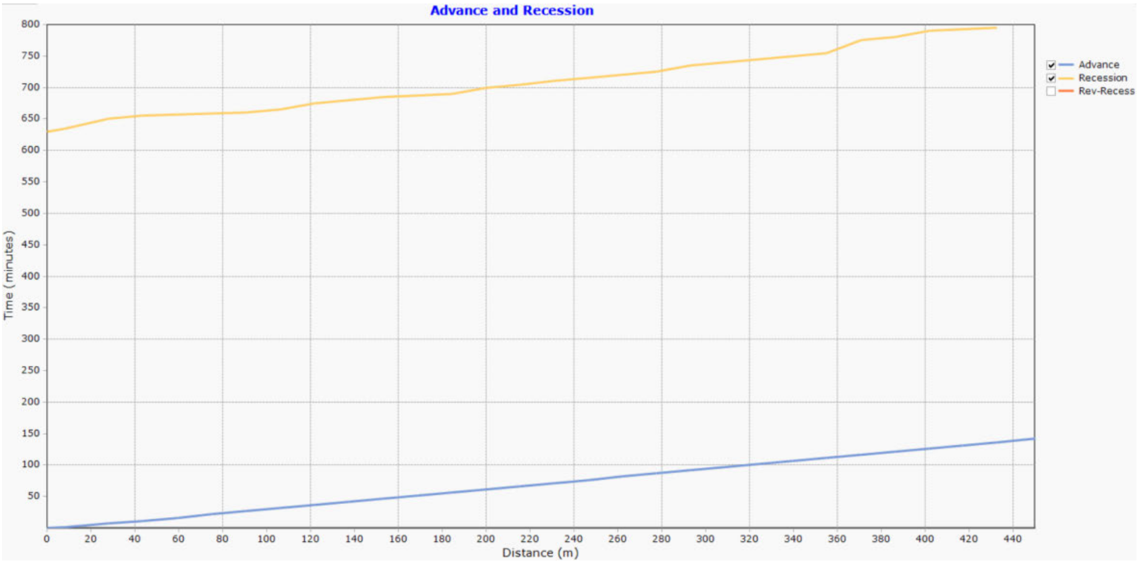


Figure 6.5 Advance and Recession wave plot as provided by SISCO software for Row 2 (tramline).

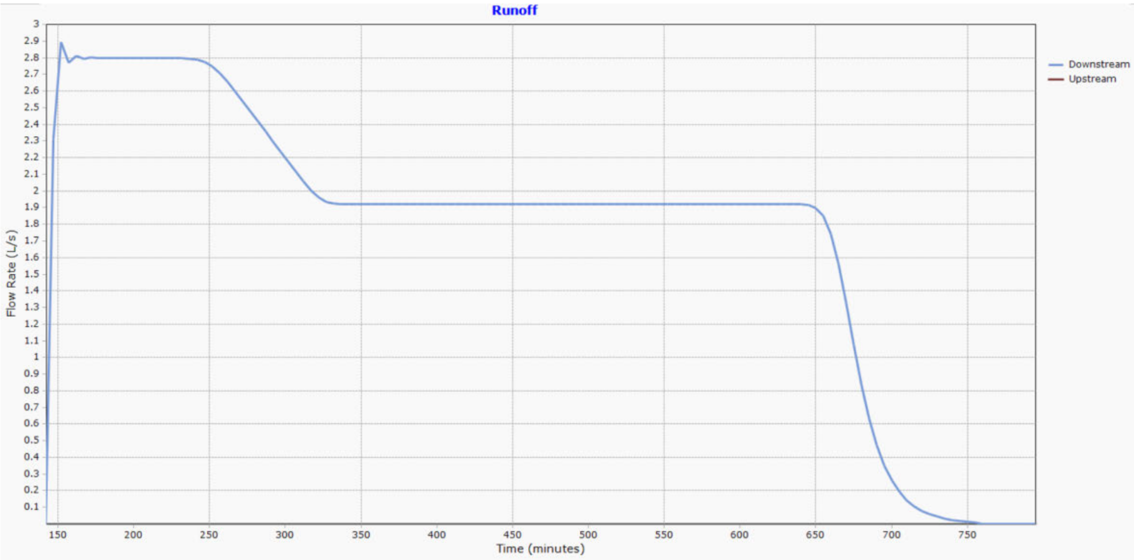


Figure 6.6 Runoff graph over the duration of the event as calculated by SISCO software for Row 2 (tramline).

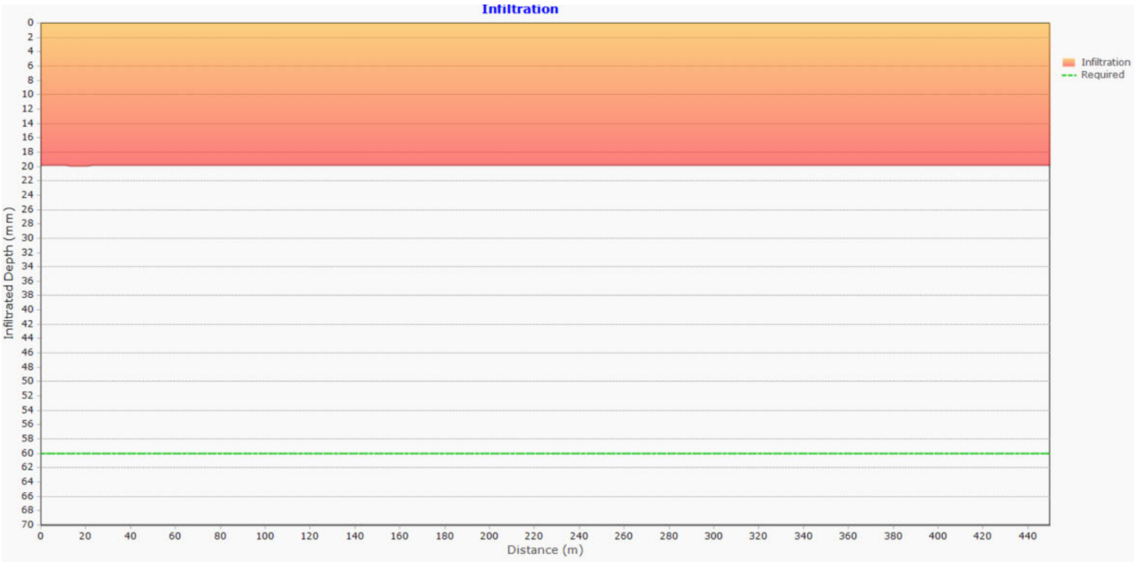


Figure 6.7 Infiltration over the length of the furrow as determined by SISCO software for Row 2 (tramline).

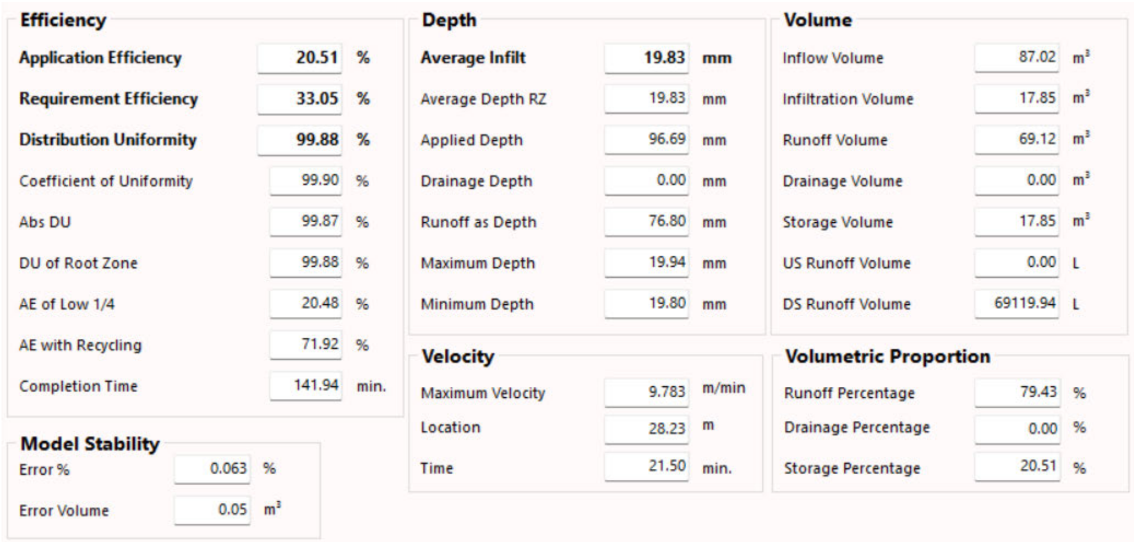


Figure 6.8 Summary of results from SISCO software for Row 2 (tramline) irrigation event.

6.4 ROW 3 (NORMAL/UNCOMPACTED) INDIVIDUAL FURROW ANALYSIS

This row (3) was considered to be normal or an uncompacted row where there is no machinery footprint directly onto the furrow. It is expected that the lack of compaction will allow for increased infiltration and application efficiency. As depicted in the advance and recession plot from SISCO of figure 6.9, the furrow was significantly slower than the tramlines. It was projected to reach the end of the field at 660 minutes into the irrigation. This was a concerning result given that the event was only allowed to run for approximately 630 minutes, ultimately meaning that some of the furrow was not irrigated at all. This is further supported from the measured raw data in chapter 5. This ultimately is the reason that row 3 does not have an accompanying runoff plot from SISCO with the water unable to reach the end, there was no water runoff recorded. Figure 6.10 below illustrates the distribution of infiltration along the length of the furrow. It furthermore shows that there was no water infiltrated past the 430 metre mark. This means that the crop past this point would most likely be stressed to a point of wilting without significant rainfall reducing yielded along this furrow. The infiltration graph also illustrates how the uncompacted furrow behaviour with approximately 115mm of water infiltrated at the start and the significant drop at the end. Thus, it can be observed that the distribution uniformity of the furrow is 58.57% significantly lower than it may be expected if the water would have reached the end. The results in figure 6.11 reveal an average infiltration depth of 93.06mm, application efficiency of 60.71% and requirement efficiency of 94.15%. These values denote a relatively efficient irrigation event however it is important to note that it was projected that the soil moisture deficit was only 60mm, denoting that there was an over watering on this occasion. It can be estimated from the SISCO modelling that around 33,000 litres of water would be lost through deep percolation in this furrow, where it is unavailable for the plant to access and thus wasted. While the normal row shows better moisture retention than the compacted trials it perhaps can be more ineffective for the farm management through over irrigating.

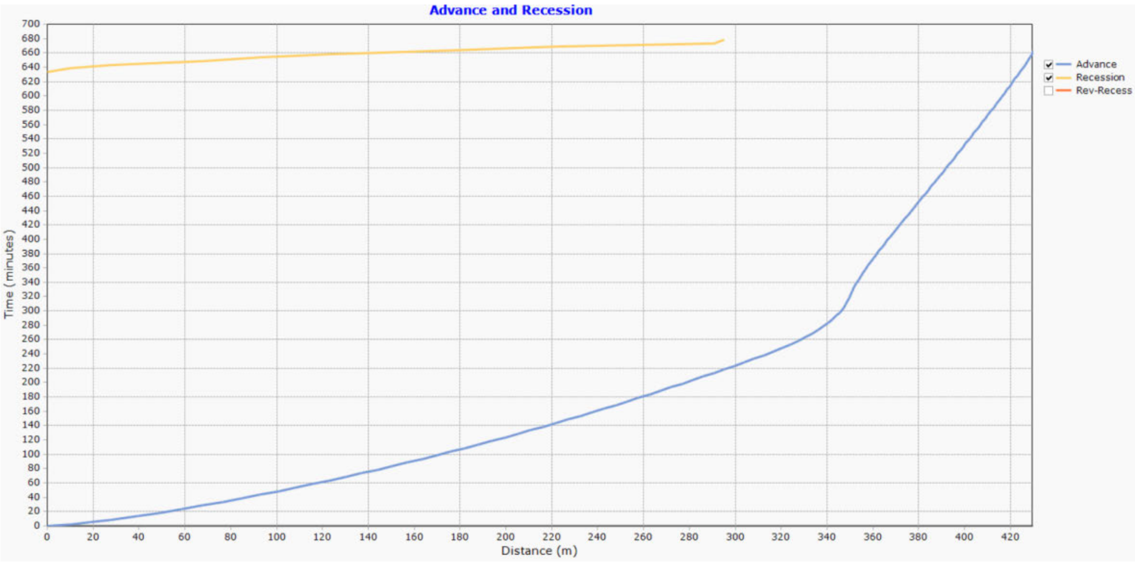


Figure 6.9 Advance and Recession wave plot as provided by SISCO software for Row 3 (normal).

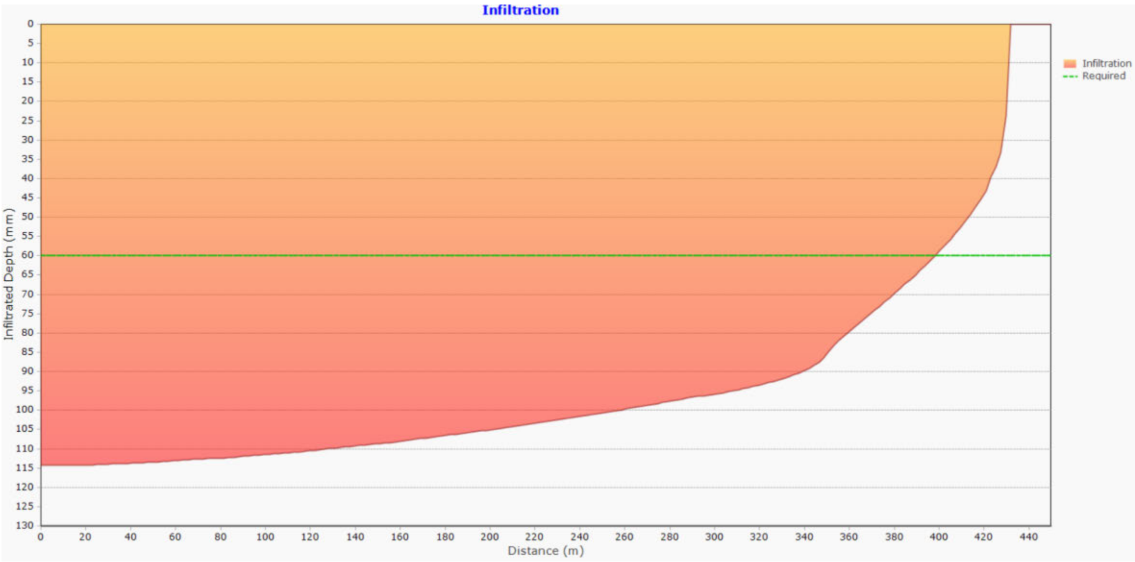


Figure 6.10 Infiltration over the length of the furrow as determined by SISCO software for Row 3 (normal).

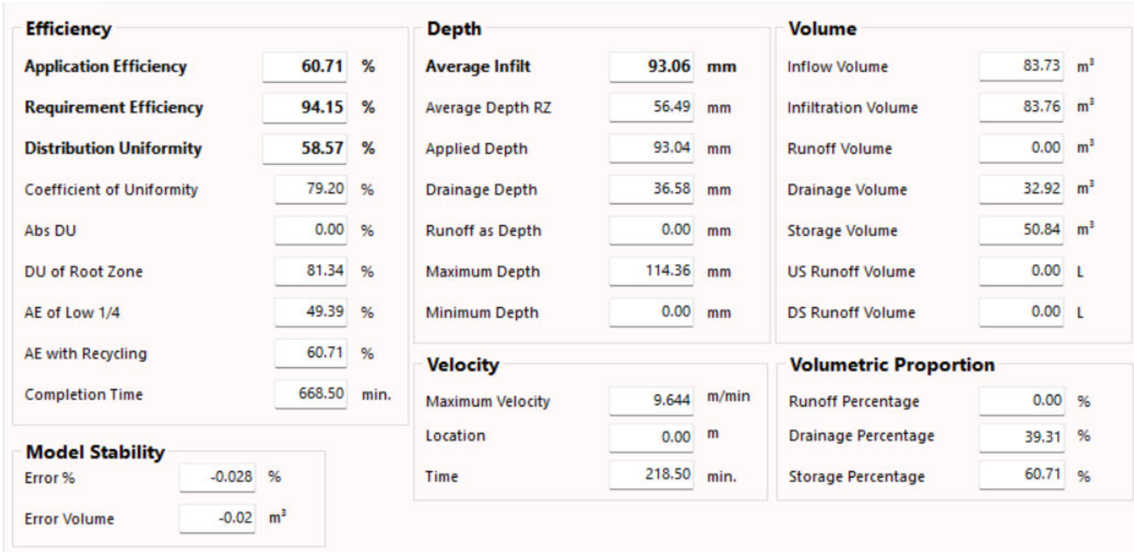


Figure 6.11 Summary of results from SISCO software for Row 3 (normal) irrigation event.

6.5 ROW 4 (NORMAL/UNCOMPACTED) INDIVIDUAL FURROW ANALYSIS

The second uncompacted or normal furrow to be analysed yielded relatively similar results to row 3 as expected. One of the foremost differences though was that row 4 reached the end of the field in the required time. More specifically it was projected to finish at exactly 630 minutes or the same time as the farm designed cutoff. This is exemplified below in figure 6.12 with the water receding relatively quickly into the uncompacted soil. The runoff was very minimal for this trial with an expected 50 litres running off around the 660 minute mark. This is considered to be a relatively good timing, as all parts of the furrow was watered with minimal requirement to pump the tail drain runoff from this row. The infiltration curve is also similar to the prior trial with a large drop off recorded from the start to the end of the furrow. It was approximated to be around 120mm of infiltration at the start dropping to around 30mm. Likewise this result projects that much of the irrigation water may be lost to deep percolation particularly with the average infiltration of 101.02mm as per figure 6.15. It also appears that the difference between row 3 and 4 is due to inflow with a projected

91.08kL for row 4 compared to only 83.73kL of row 3. This lower flow is potentially the reason that row 3 was unable to reach the end of the field. Overall, the results showed that the uncompacted furrow is more effective at fulfilling the field requirement with better application efficiency also, however it still has reasonably high wastage from deep percolation.

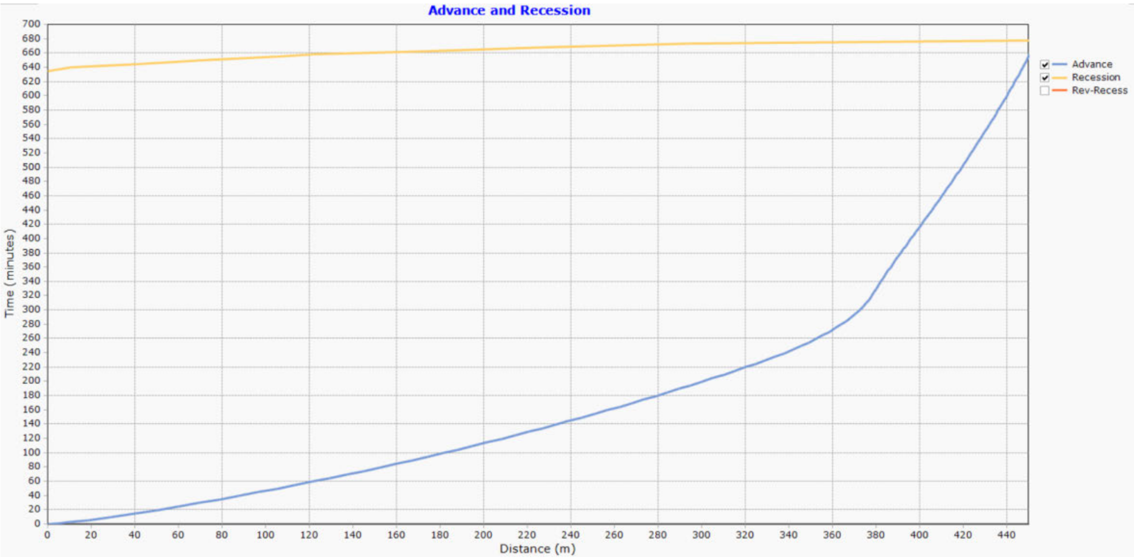


Figure 6.12 Advance and Recession wave plot as provided by SISCO software for Row 4 (normal).

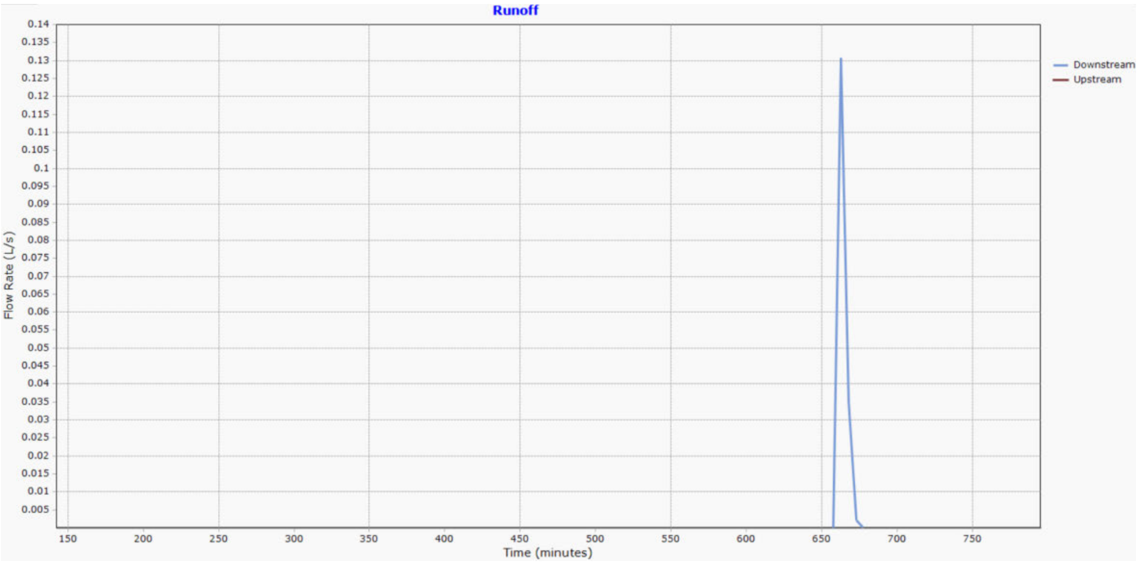


Figure 6.13 Runoff graph over the duration of the event as calculated by SISCO software for Row 4 (normal).

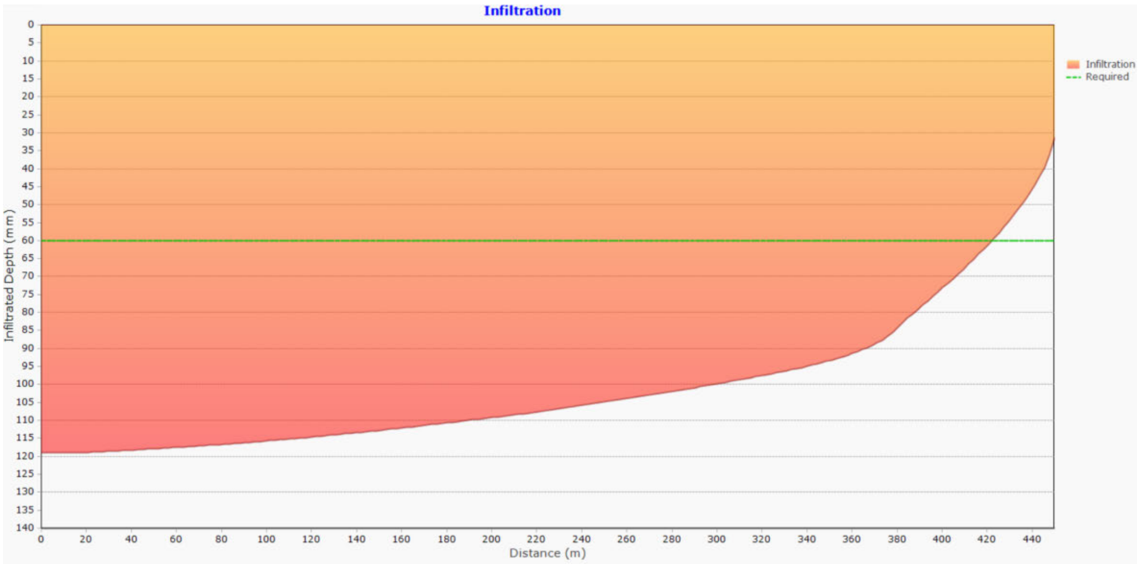


Figure 6.14 Infiltration over the length of the furrow as determined by SISCO software for Row 4 (normal).

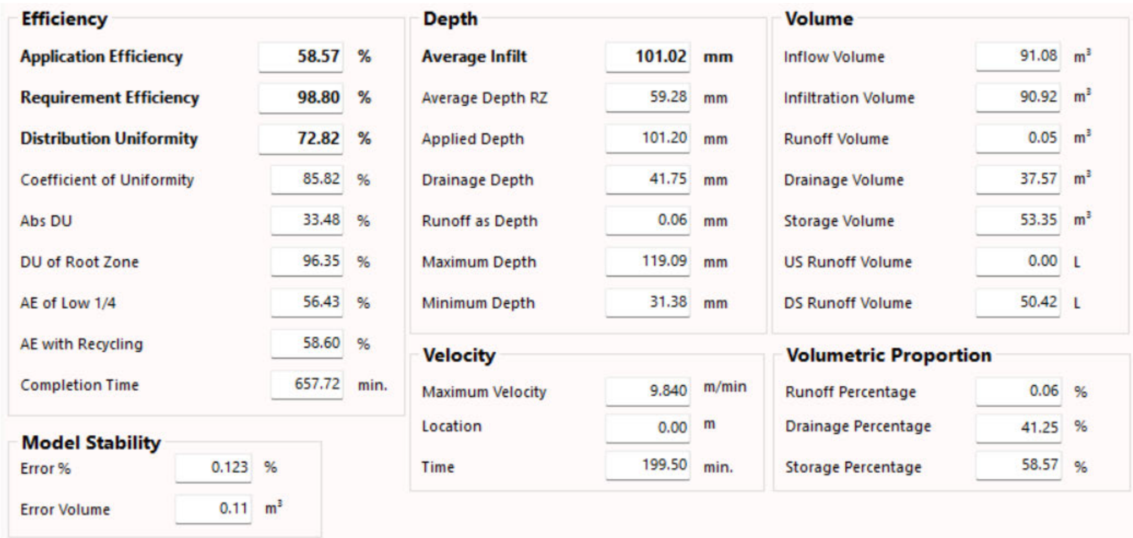


Figure 6.15 Summary of results from SISCO software for Row 4 (normal) irrigation event.

6.6 ROW 5 (PLANTING TRACKS) INDIVIDUAL FURROW ANALYSIS

The final analysis was to be completed on row 5 and 6 which were taken from the planting wheel track furrows. This means that it would experience some level of compaction but not as much as the traditional tramlines would. It was therefore theorised that the planting track furrows would exhibit behaviours in between the tramline and normal/uncompacted furrows. Figure 6.16 below illustrates the projected advance and recession lines for row 5 from the collected data. It suggests that the advance wave will reach the end of the field around 220 minutes into the irrigation event. This is significantly faster than the uncompacted furrows however still slower than the compacted tramlines as expected. The calculated runoff from SISCO (figure 6.17) suggests that there is still a considerable amount of water being collected in the tail drain over the entire irrigation event, with it steadying around 1L/s. The infiltration data may have yielded the best in terms of reaching requirement efficiency and distribution uniformity. Figure 6.19 portrays that the furrow fulfilled 99.99% of the required 60mm of infiltration and reached 93.42% in terms of uniformity. This ultimately means that the infiltration maximum started around 70mm and dropped only 10mm to approximately 60mm at the end of the furrow. This is an ideal infiltration curve however the overall irrigation application efficiency is still unacceptable as around 30,000 litres of the water left the field as runoff and required recycling to be used again. The model yielded an application efficiency of 60.72% on this particular furrow with the slight compaction of the soil improving the performance. Whilst the results show some of the better efficiency can occur with this level of compaction it does not account for the other side effects of compaction on the growth of the corn crop. It can therefore be concluded that row 5 data recorded and processed suggests that compaction can reduce infiltration but increase the uniformity of infiltration as a whole.

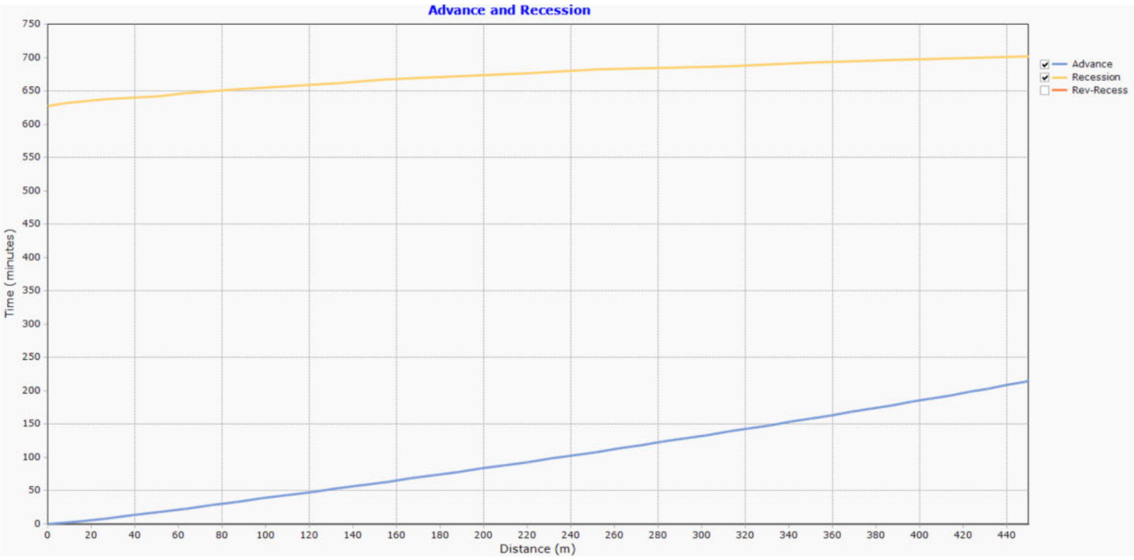


Figure 6.16 Advance and Recession wave plot as provided by SISCO software for Row 5 (planting tracks).

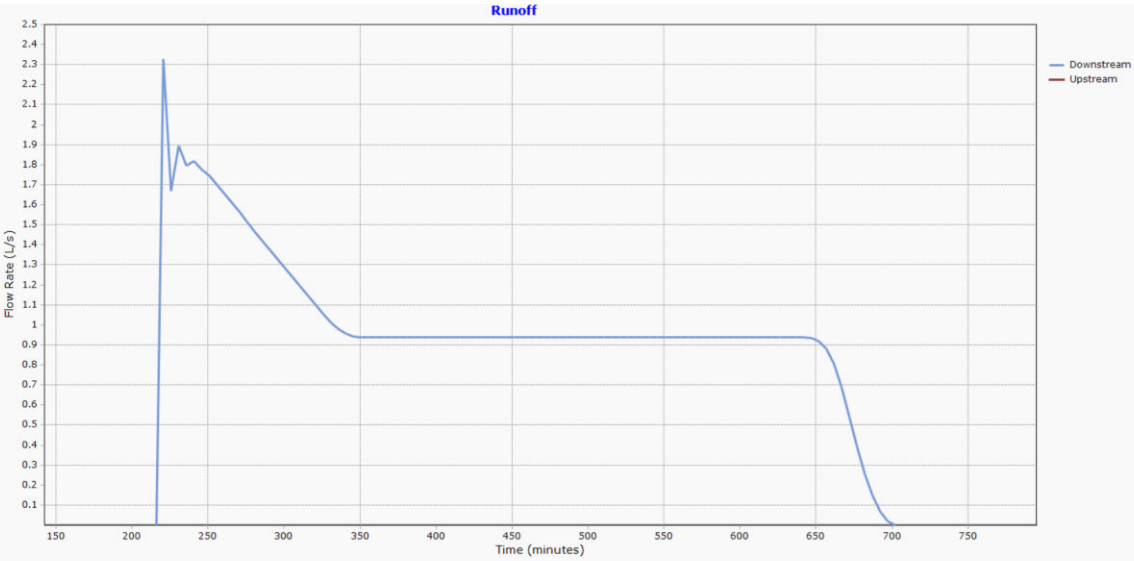


Figure 6.17 Runoff graph over the duration of the event as calculated by SISCO software for Row 5 (planting tracks).

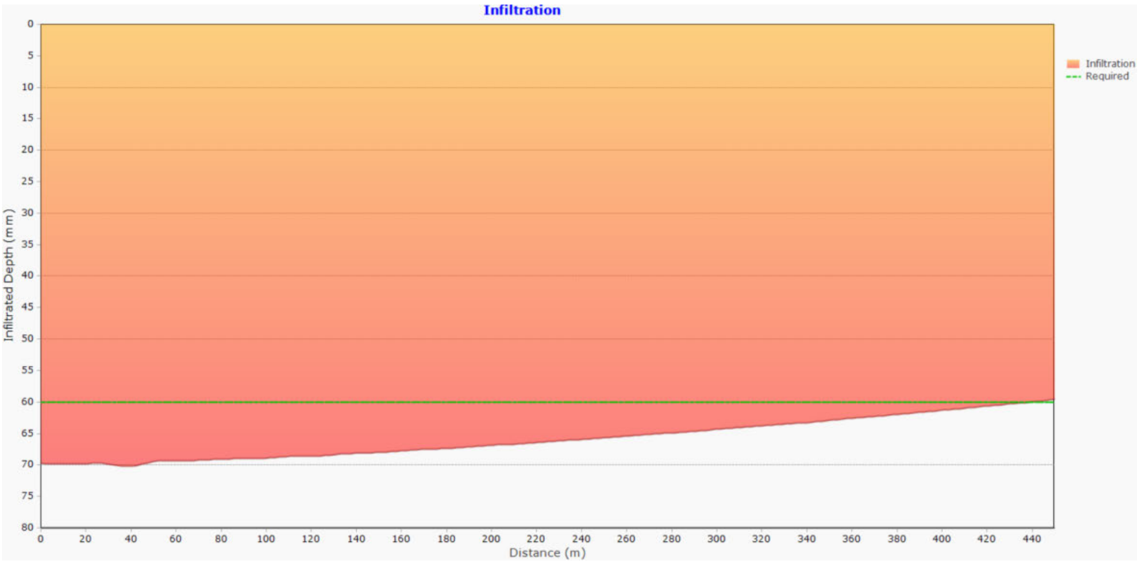


Figure 6.18 Infiltration over the length of the furrow as determined by SISCO software for Row 5 (planting tracks).

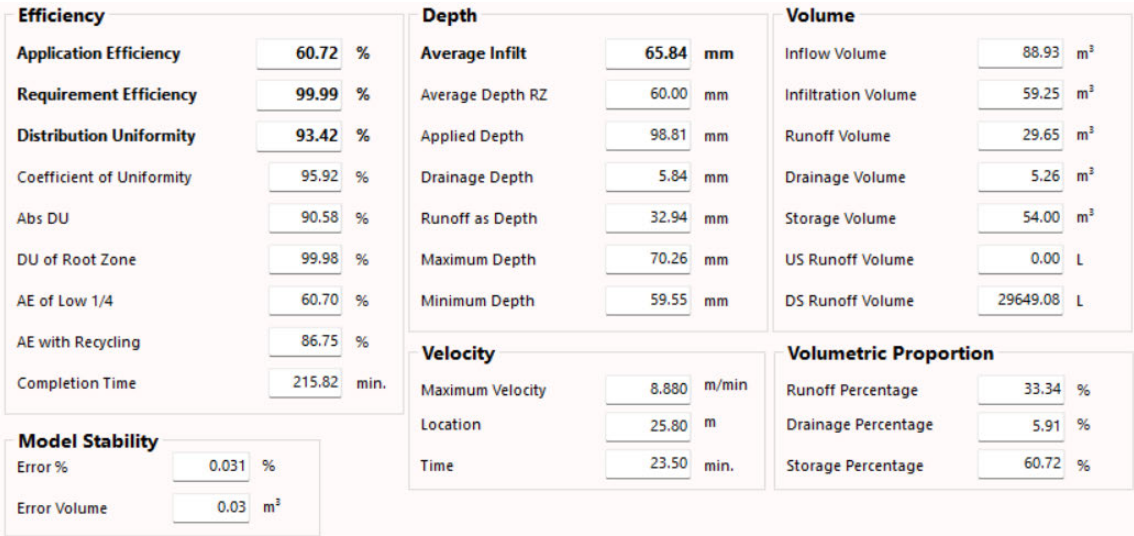


Figure 6.19 Summary of results from SISCO software for Row 5 (planting tracks) irrigation event.

6.7 ROW 6 (PLANTING TRACKS) INDIVIDUAL FURROW ANALYSIS

The final analysis was completed on row 6 which was representative of the planting tracks furrow. As mentioned previously this furrow experiences some level of compaction which is expected to have an impact on the irrigation infiltration and performance. With reference to figure 6.20 below, the advance and recession wave is very similar to that of row 5 test. The advance appears to reach the end of the furrow in around 220 minutes with a very comparable recession curve. Figure 6.21 also shows a considerable amount of runoff after the advance has reached the end of the field with slightly higher runoff volumes recorded in comparison to that of row 5. The infiltration curve is relatively uniform in comparison to other uncompacted trials starting at approximately 59mm and dropped to only 52mm at the end of the field. This is why the results summary in figure 6.23 project a distribution uniformity value of 94.73% and a reasonably good requirement efficiency of 92.73%. These values demonstrate that the majority of the field is receiving close to the required 60mm of water for the benefit of the crop. Whilst it boasted a relatively high application efficiency value of 57.13% it still predicts that the runoff from the furrow alone is over 37,000 litres. This potentially means that the application efficiency still can be improved but altering factors like the flow rate and/or duration of the irrigation.

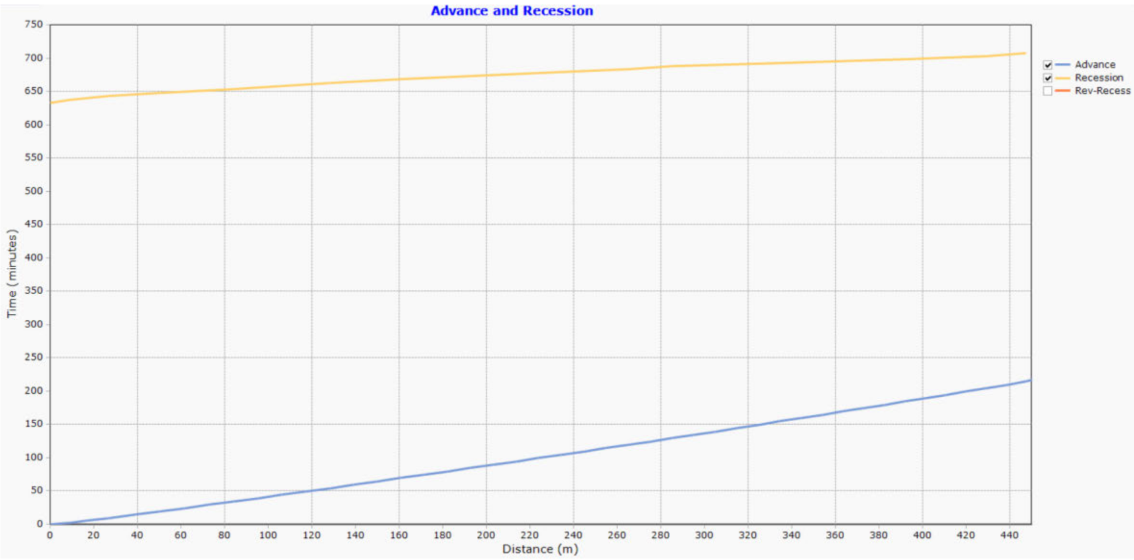


Figure 6.20 Advance and Recession wave plot as provided by SISCO software for Row 6 (planting tracks).

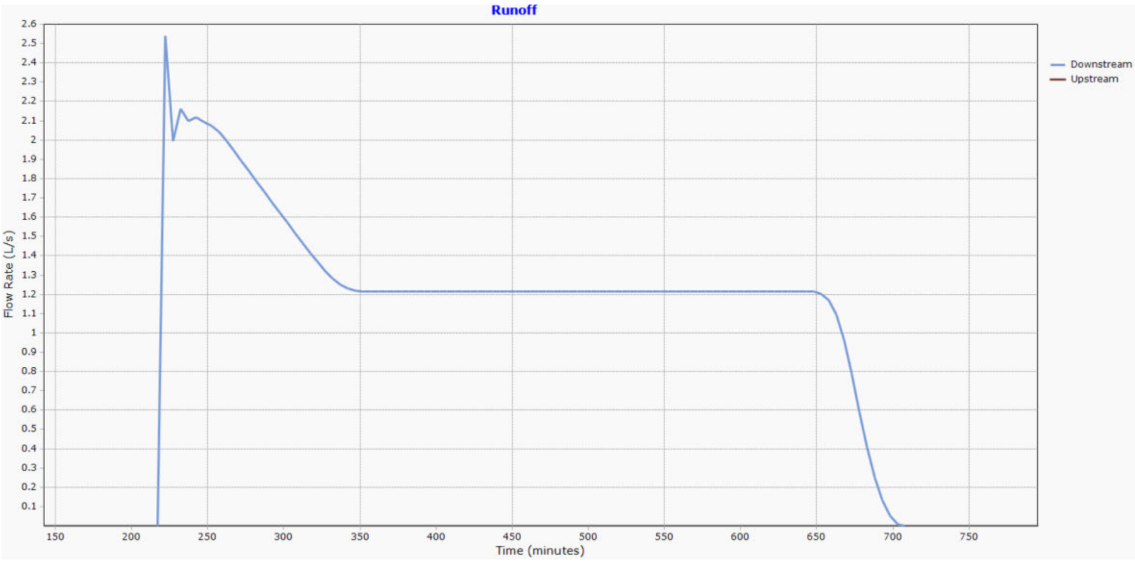


Figure 6.21 Runoff graph over the duration of the event as calculated by SISCO software for Row 6 (planting tracks).

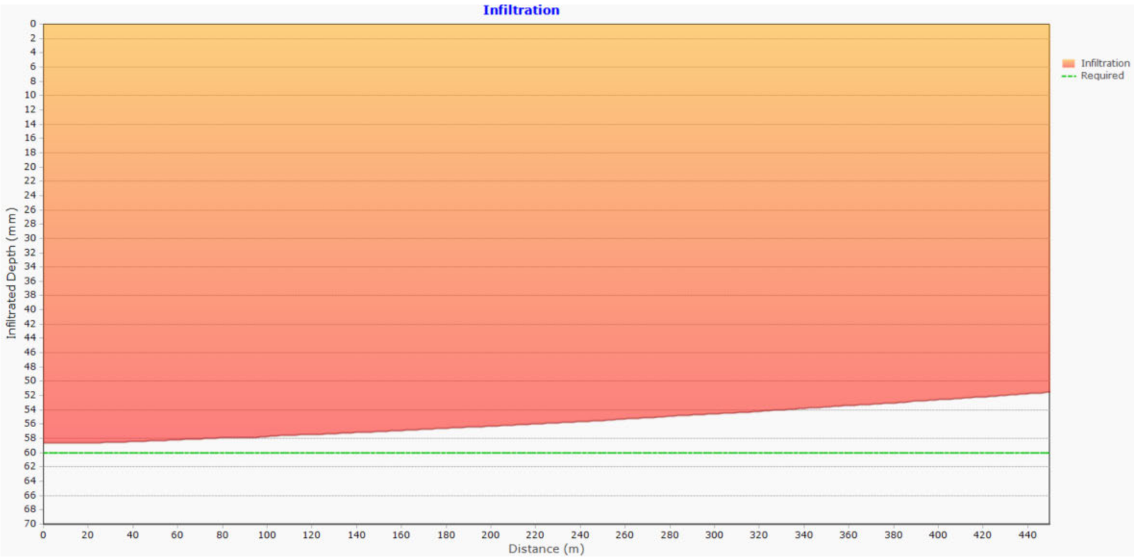


Figure 6.22 Infiltration over the length of the furrow as determined by SISCO software for Row 6 (planting tracks).

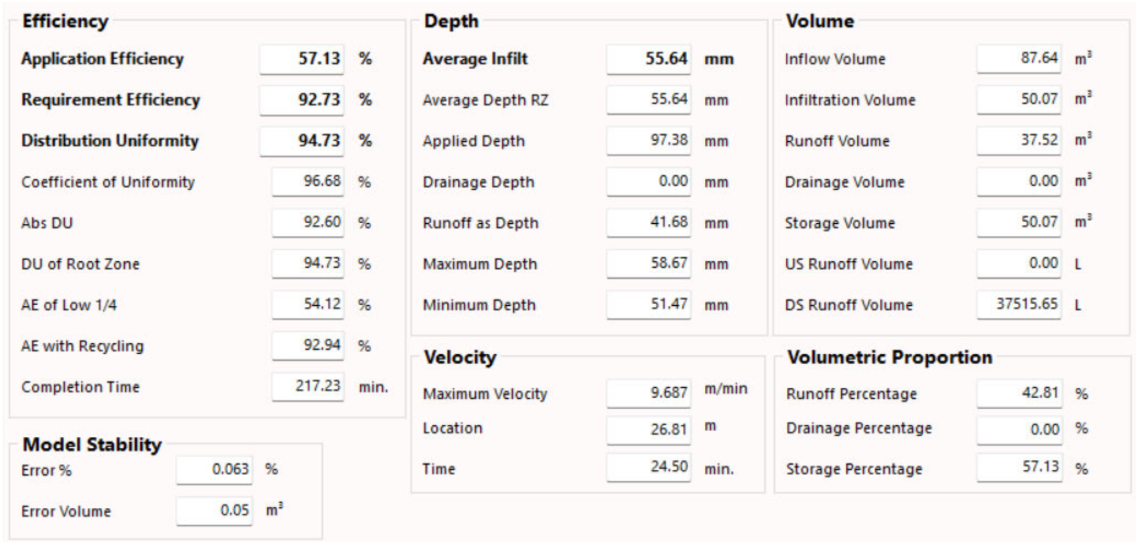


Figure 6.23 Summary of results from SISCO software for Row 6 (planting tracks) irrigation event.

6.8 COMPARISON OF RESULTS

The first major aspect to compare is the advance wave or rate at which the water moves down the furrow to the end of the field. Utilising SISCO software, the measured advance data from chapter 5 could be extrapolated and plotted as per figure 6.24 below. It accurately depicts the movement of water from the start of the irrigation along the length of the furrow over the duration of the event. One of the most important aspects observed from the figure is the relative proximity and resemblance between the two furrows in the same classification. This is exemplified in figure 6.24 where the planting track furrows both reached the end within 5 minutes of each other and how the normal/uncompacted furrows exhibit similar curve shapes. There appears to be no obvious outliers in the data despite the potential slight inconsistencies in flowrates and soil characteristics. Using table 6.1 just below it can be seen what the differences to the average flow rate is for each of the trail furrows. The largest difference is between row 3 which observes an average of 2.18 L/s compared to row 4 of 2.36 L/s. This inconsistency may have been the reason that row 3 was unable to reach the end of the field particularly compared to the other normal/uncompacted trial. Ultimately there still appears to be relatively low changes in average flow rate with 0.06 L/s difference recorded for both the planting track furrows and the tramlines trials. The table therefore validates that whilst there is still some fluctuation in flow rate, the major change to the advance wave will be a result of the compaction.

Table 6.1 Comparison of average flow rate per furrow over the duration of the irrigation.

	Average Flow Rate Over Entire Irrigation (L/s)
Row 1 Tramline	2.21
Row 2 Tramline	2.27
Row 3 Normal	2.18
Row 4 Normal	2.36
Row 5 Planter	2.33
Row 6 Planter	2.27

The results prove that the areas of similar compaction will record similar advance wave data. Providing each furrow receives a similar inflow it is logical to examine the relationships between compaction and irrigation. As theorised the increased compaction appears to reduce the time taken for the advance wave to reach the end of the field. This is demonstrated in the figure where the tramlines or most compacted trials were significantly faster than other trials to reach the end. More specifically it was approximately 60 minutes faster than the planting track furrows and 500 minutes quicker than uncompacted trials. There appears to be a rather significant difference between the planting track furrows 220 minute completion time the 660 minutes for normal/uncompacted furrows. Whilst the planting tracks still do not experience the same level of compaction as the tramlines, it does show that any change in compaction will have a dramatic impact on the irrigation performance. Whilst countless research articles has concluded a similar concept on compaction and infiltration, quantified data is imperative for developing the optimised irrigation strategy, for a field with variable compaction.

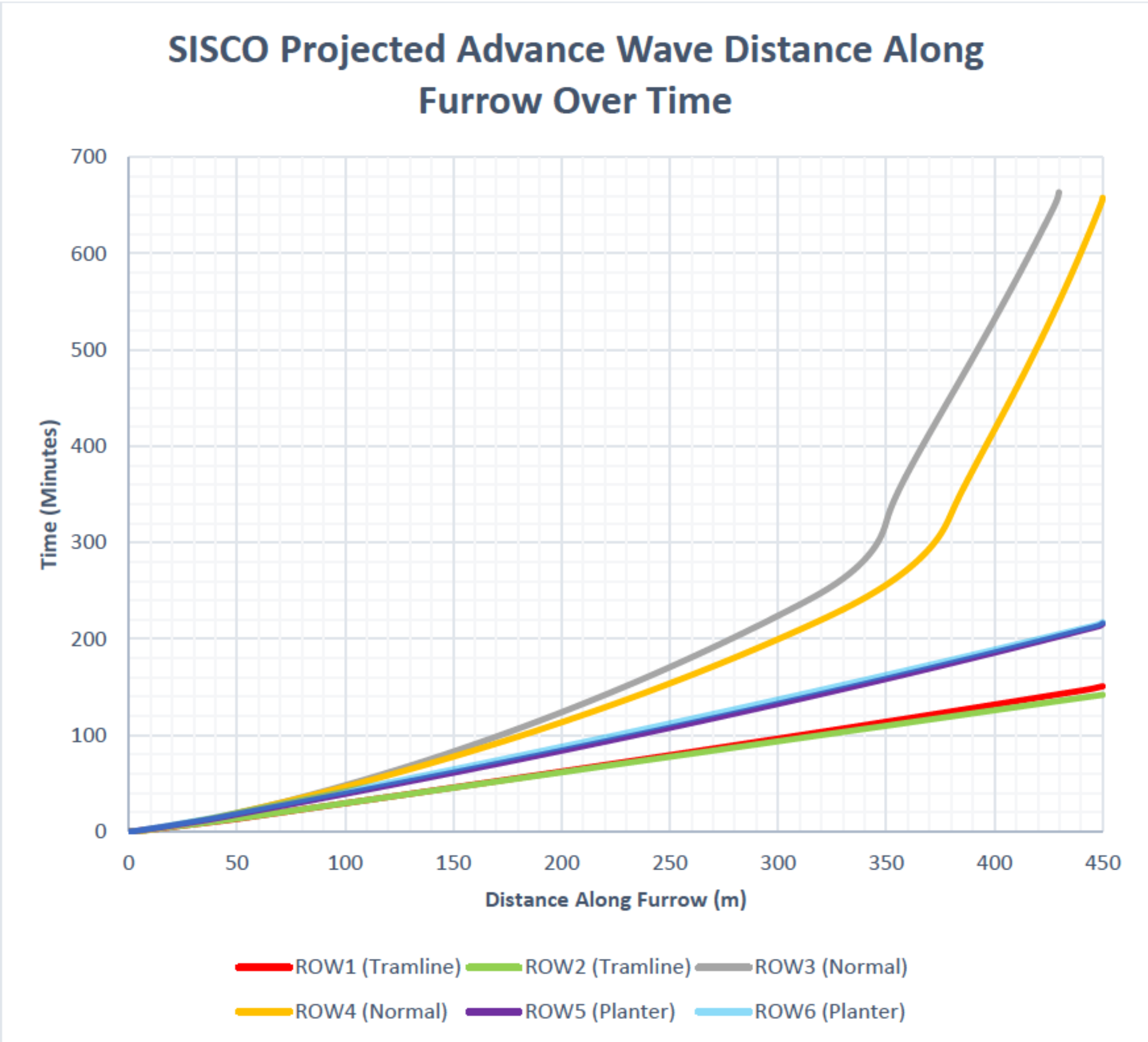


Figure 6.24 SISCO projection of advance wave movement along each furrow over time.

As seen throughout the SISCO analysis the advance data ultimately correlates with the amount of infiltration experienced within each furrow. The model and simulation of the irrigation event produced infiltration data that is graphical presented below in figure 6.25.

This data accuracy is proven from prior research to reflect high accuracy to the real world infiltration values. One of the most notable aspects of the figure is that the normal uncompacted furrows of 3 and 4 both exhibit similar behaviour, starting with a high value around 115mm and dropping significantly at the end of the furrow. In the case of row 3 specifically it was unable to reach the end of the field ultimately affecting the corn growth in the last 20 metres of the field length. Interestingly the compacted trials appear to have a more uniform distribution in regard to the infiltration, leading to the conclusion that the higher levels of compaction results in a more uniform dispersion of water. It is however revealed that the increased level of compaction appears to reduce the amount of infiltration in the soil, potential decreasing the soil water holding capacity altogether. This is exemplified in the graph where the tramline rows only infiltrate around 20mm and 38mm respectively. The furrows which experienced compaction only from the planting operations have higher infiltration values of 58mm and 65mm. This amount of infiltration matches well with the soil deficit where it was assumed that the corn crop will require only 60mm from the irrigation event. This indicates that some of the infiltrated water from the uncompacted furrows may be lost through deep percolation and is therefore not effective for the plant. There are many notes from the comparison regarding infiltration, however the simulation in this example reveals a relationship where less compaction results in a higher infiltration. This is not a new conclusion however this project provides numerical data which could be used to produce a more effective and efficient irrigation plan.

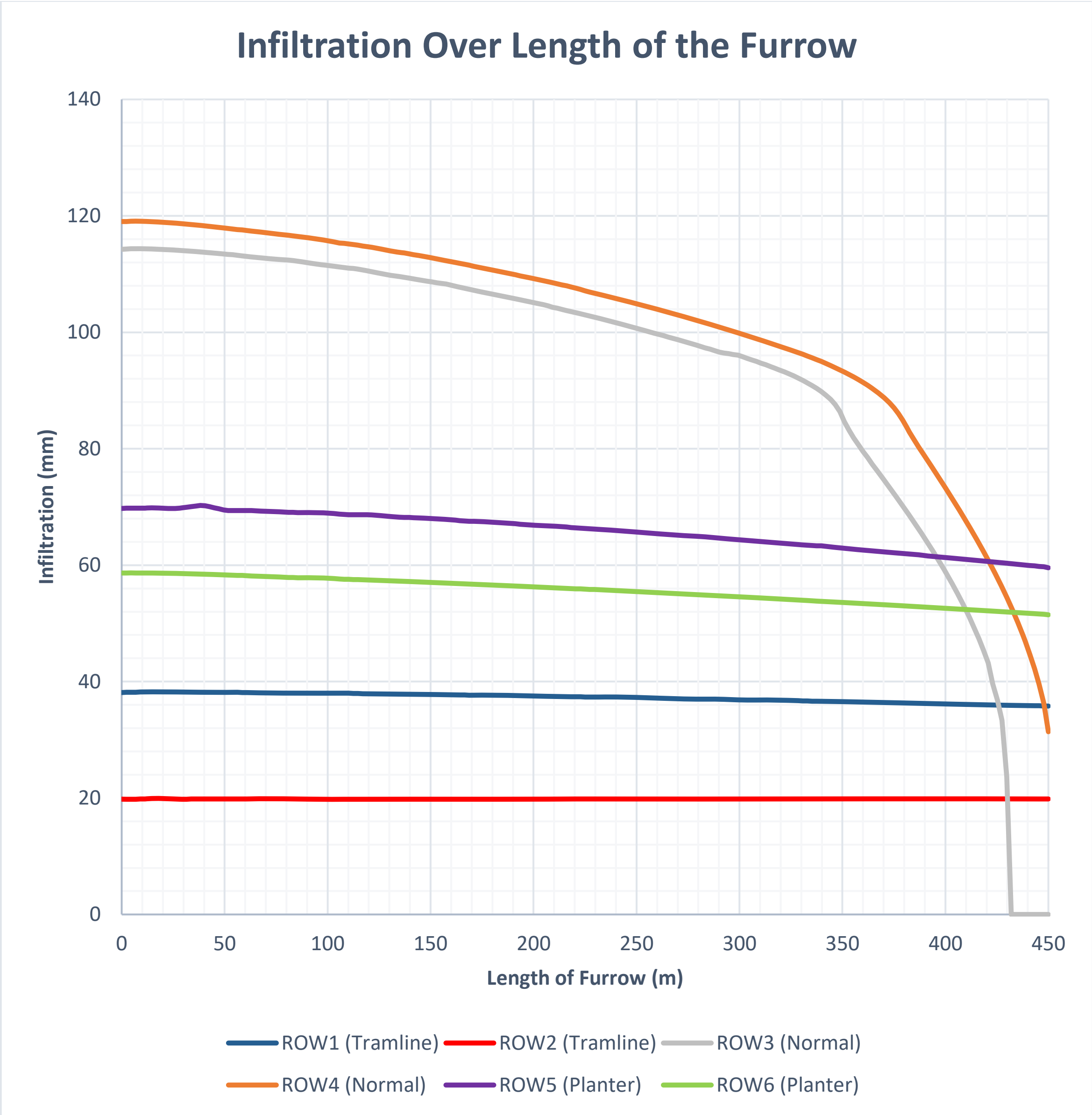


Figure 6.25 SISCO calculated infiltration over the length of each furrow analysed.

The project has successfully collected raw data for simulating through SISCO software in the endeavour to evaluate the overall performance of each furrow. Table 6.2 below is combination of the most valuable results produced from the individual furrow analysis completed in the sections above. The first aspect is perhaps one of the most important with the application efficiency determining in a percentage how much water was made available directly to the plant. The results appear to be similar for the planting tracks and the normal uncompacted furrows generally observed around the 58% to 60% mark. This is a dramatic difference to the tramline values calculated to be 20.51% and 39.5% respectively. It demonstrates that the level of compaction in the tramline is having an excessive detrimental impact on the performance. It does however appear that the presence of some compaction in the planting track furrows has not dramatically impacted on the overall performance as of yet. Whilst SISCO is also able to calculate the application efficiency with recycling of runoff water, this is not a major objective for the project as it induces more energy requirements to pump the water back into dams and also creates more loss in the form of evaporation and unwanted infiltration. The requirement efficiency value is also an important aspect with it reflecting in a percentage the amount of water that was received out of the 60mm assumed deficient. The lesser values indicates that the corn crop both sides of the furrow is not receiving enough water and therefore will most likely experience stress and wilting leading to a reduced yield. In similar fashion to the application efficiency, the tramlines has only filled 33.05% and 62.09% of the requirement. This is vastly less than the normal and planting tracks furrows which are around 95%, fulfilling majority of the requirement. As discussed previously it was found that the distribution uniformity for infiltration was higher for furrows with more compaction. The table below illustrates a major drop from the above 90% values calculated for the tramline and planting tracks to approximately 65% for the uncompacted trials. Whilst the infiltration is more uniform with higher compaction it is proven to reduce the amount of infiltration. The average infiltration in the high compaction tramline trials was observed to be 19.83mm and 37.26mm. As there became less compaction the infiltration value increased with the planting track furrows recording 55.64mm and 65.84mm separately. The infiltration continued to rise further for furrows with minimal to no compaction with values as high as 93.06mm and 101.02mm. Utilising this information will be crucial for developing an optimised irrigation strategy that reduces both runoff and deep percolation from excess infiltration. The results also shows that the inflow data had some variation, however, not enough to prove any discrepancies in the data. This was discussed previously with the differences in flow rate per furrow being a major contributor for this recorded variation. As anticipated the level of compaction has an impact on the amount of runoff projected. More specifically the higher compaction causes more runoff, with the tramlines recording values in excess of 50,000 litres. The normal furrows were barely able to reach the end of the furrow in the time provided with only 50 litres of runoff from row 4. The planting furrows split the difference with the presence of some compaction causing runoff values around 30,000 litres. Ultimately the data proves that the tramlines, planting tracks and normal/uncompacted furrows will behaviour differently during an irrigation event and thus an optimisation strategy could be beneficial to improving irrigation performance.

Table 6.2 Comparative table of key parameters surrounding the performance of each of the 6 furrows analysed.

	Application Efficiency (%)	Requirement Efficiency (%)	Distribution Uniformity (%)	Average Infiltration (mm)	Minimum Infiltration (mm)	Maximum Infiltration (mm)	Inflow Volume (m^3)	Runoff Volume (m^3)
Row 1 Tramline	39.5	62.09	97.2	37.26	35.79	38.28	84.89	51.33
Row 2 Tramline	20.51	33.05	99.88	19.83	19.8	19.94	87.02	69.12
Row 3 Normal	60.71	94.15	58.57	93.06	0	114.36	83.73	0
Row 4 Normal	58.57	98.8	72.82	101.02	31.38	119.09	91.08	0.05
Row 5 Planter	60.72	99.99	93.42	65.84	59.55	70.26	88.93	29.65
Row 6 Planter	57.13	92.73	94.73	55.64	51.47	58.67	87.64	37.52

6.9 EVALUATION OF ENTIRE FIELD

The project has successfully investigated and quantified the impact of compaction on irrigation performance, with the results strongly supporting that higher compaction leads to reduced infiltration. Whilst the testing was only conducted across 2 of each tramlines, planting tracks and normal furrows, this does not reflect their real field importance. As referred to previously in the project there is only 2 tramlines out of every 12 furrows. Furthermore, there is only 2 planting tracks and 8 normal/uncompacted furrows across every 12 furrows. This ultimately means that the overall evaluation of the irrigation performance must be weighted according to the presence of that furrow classification. If a strategy was only proposed to benefit the tramline furrows, then it would only be accounting for 16.67% of the entire field. The goal of this project will be to evaluate if there is potential to improve the irrigation efficiency across all furrows and whether one furrow can truly be reflective of the entire field.

A technique is proposed to properly weight the relative importance of the compacted furrows. The pattern of wheel traffic across the field repeats every 24 metres, with irrigated furrows on a 2m spacing. This is exemplified in figure 6.26 which illustrates the 12 furrow pattern that can be used to represent the entire field. These 12 furrows contain 2 tramlines and 2 planting tracks with the remaining 8 being normal or uncompacted. In particular the tramlines are represented in red, planting tracks in green and the normal in blue.

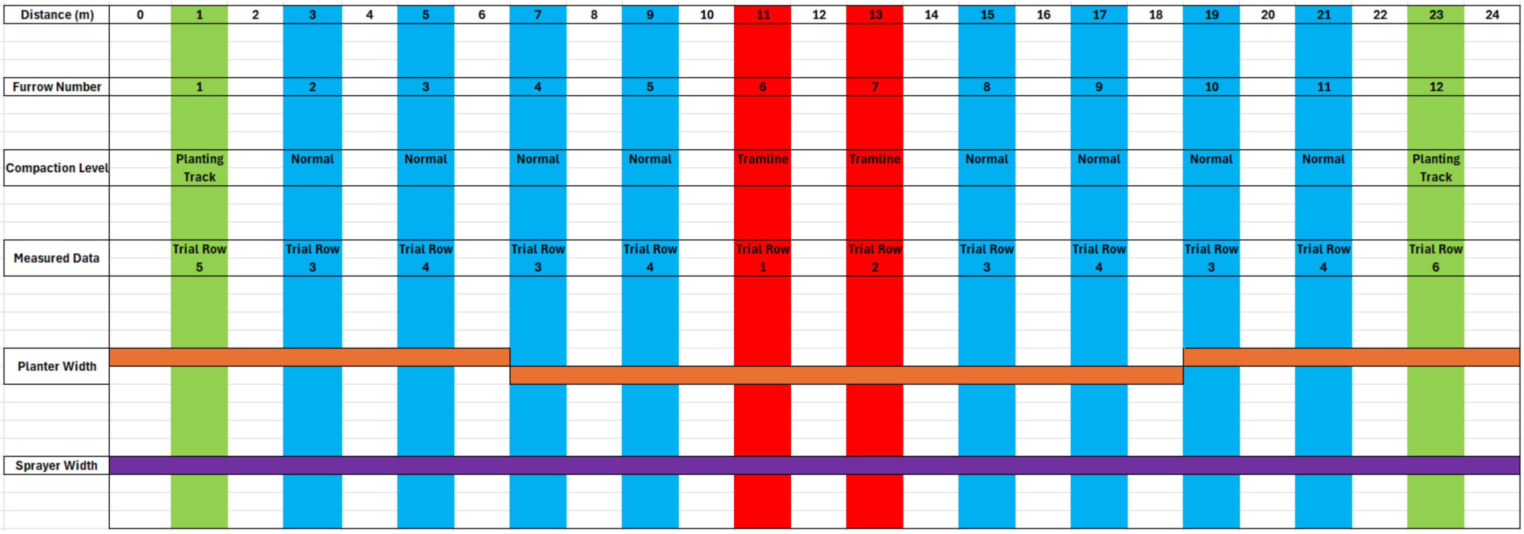


Figure 6.26 Example of repeating furrow pattern to represent the entire field.

The measured furrows include 2 tramlines, 2 planter tracks and 2 uncompacted furrows. To create the representative 12 furrow, sample each uncompacted furrow is repeated four times in the data set such that the two measured furrows become eight uncompacted furrows. The measured data numbers in figure 6.26 correspond to the numbering used previously in this document with furrows 1 and 2 being the tramlines, furrow 5 and 6 being the planting traffic and 3 and 4 being the uncompacted furrows. The final result is a 12 furrow sample which can be simulated within the Multi Furrow simulation in SISCO. This 12 furrow "field" will be the basis for the analysis in the proceeding chapter.

Table 6.3 generated below is completed with the weighted values of all irrigation performance related aspects across the entire field and also for the 12 furrows which is one sprayer width of 24 metres. The values are assuming through satellite imagery that the field is 780m in width accounting for 390 individual furrows on 2 metre spacings. From the data it can be concluded that the application efficiency for the field was around 54.58%, which is in the lower half of irrigation performance in Australia. The requirement efficiency is 88.31% which is relatively satisfactory with majority of the field receiving the minimum of 60mm that is assumed to be required by the corn crop. It also illustrates a distribution uniformity value of only 75.90% which suggests there is still a reasonable amount of variation recorded in the field. Furthermore, to support the average infiltration throughout the entire field is 79.57mm which is above the required amount and suggests that the plants in general are receiving enough water. This does however suggest that a great deal of the water is being lost through deep percolation. This is generally a large waste with it projected to have approximately 9.1 ML is not available to the plant and lost to deep water storage. Overall, the inflow volume from the measured data assumes the entire field will receive 34.05 ML with a total of 6.10 ML accounting for runoff. This information suggests that close to 18% of water applied is being collected in the tail drain and 26.7% is lost in deep percolation. In total around 44.7% is not being utilised by the plant from the collected irrigation event data. Ultimately the irrigation overall performance is within acceptable range and providing the majority of crops with enough moisture, however there are adjustments that can be made to improve the irrigation performance as a whole.

Table 6.3 Evaluation of irrigation performance for the entire field.

	Application Efficiency (%)	Requirement Efficiency (%)	Distribution Uniformity (%)	Average Infiltration (mm)	Inflow Volume (m^3)		Runoff Volume (m^3)	
					(m^3)	(ML)	(m^3)	(ML)
Entire Field	54.58	88.31	75.90	79.57	34050.90	34.05	6104.15	6.10
12 Furrows / 1 Sprayer Width					1047.72	1.05	187.82	0.19

6.10 CONCLUSION OF SISCO ANALYSIS

Throughout the chapter SISCO has successfully performed individual furrow analysis to effectively evaluate the impact of compaction on irrigation performance. The results were noted throughout to have low error ratings with 0.123% at the highest, suggesting that there was excellent overall model stability for each furrow examined. The processing of the data further supported that there is a relationship between compaction and irrigation performance, observing that higher compaction reduced infiltration and increased the advance movement speed. This ultimately led to a reduced application efficiency but an increase in the uniformity of infiltration across the length of the furrow. Uncompacted soils were observed to have vastly higher infiltration characteristics with data suggesting that much of the moisture was being lost through deep percolation. Ultimately SISCO individual analysis provided information on the soil characteristics that can be utilised to develop a more effective and efficient irrigation system.

CHAPTER 7 OPTIMISED IRRIGATION PROPOSAL

7.1 INTRODUCTION TO SISCO OPTIMISING

The SISCO simulating aspect has been demonstrated throughout the previous chapter, however this specific chapter investigates SISCO's advanced functions that include multi furrow analysis and optimisation features. This aspect of SISCO has not yet been rigorously tested however it incorporates many of the crucial aspects from the individual furrow analysis to simply compute in a more effective and uniform measure. The optimisation feature is able to utilise the collected data and produce results for a theoretical irrigation in a timely manner. This particular feature of the software with further research and commercialisation has the potential to be integrated into irrigation technology for real time optimisation.

This chapter presents three separate irrigation proposals with assessments conducted on the overall viability of each option. They are listed below:

1. Struanville Farming Co desired flowrate and duration
2. Optimised duration with constant flowrate
3. Optimised flowrate and duration design

The first one is evaluating the performance of an irrigation event that goes as planned by the Struanville farming management team. This will include a constant flowrate and a set duration for the irrigation event to occur. The next strategy will utilise the optimisation feature of SISCO to select the best cutoff time for both requirement and application efficiency across the entire representative twelve furrow set. This approach will be more cost effective and time efficient, without any need to make dramatic investments or irrigation field/equipment adaptations. The final one is still aimed at being a practical optimisation solution, however it changes the flowrate and the duration of the event to yield the best results for farmers.

These irrigation strategies will be utilising the multi furrow input function from SISCO's advance version that is depicted in figure 7.1 below. The multi furrow functionality enables the user to enter selected input variables for each furrow. In figure 7.1 different soil infiltration parameters have been entered for each of furrow. As referred to previously the analysis will be conducted on 12 furrows that reflect the pattern from the field at Struanville Farming co. This will consist of 2 tramlines, 2 planting track furrows and 8 uncompacted/normal furrows. This pattern will be repeated throughout the entire field and therefore the overall efficiency values in percentages can be reflective of the entire field. As outlined in the previous section SISCO utilised the individual furrow analysis to calibrate the infiltration parameters a, k and f0 in accordance with the collected field data. These important values provide an outline on the behaviour of the soil when irrigated and are placed into the multi furrow analysis section as outlined in the below figure. These infiltration parameters are assumed to be reflective of the entire field, with the prior research showing a strong correlation between furrows that experience similar compaction levels.

The advanced version of SISCO includes an optimisation tool (figure 7.2) which involves SISCO performing a series of calculations to evaluate irrigation performance while varying two predetermined parameters over specified ranges. The parameters that can be chosen include flowrate, duration/time, slope and also field length. The slope and field length parameters in particular would be most beneficial in the designing of a field as it can give feedback as to the optimal slope and length in a theoretical sense. This however is not applicable for this research as it would be both costly and labour intensive to change these factors. Therefore, the flow rate and duration of irrigation will be altered and investigated throughout this chapter to provide valuable advice on improving irrigation performance for fields that experience variable compaction.

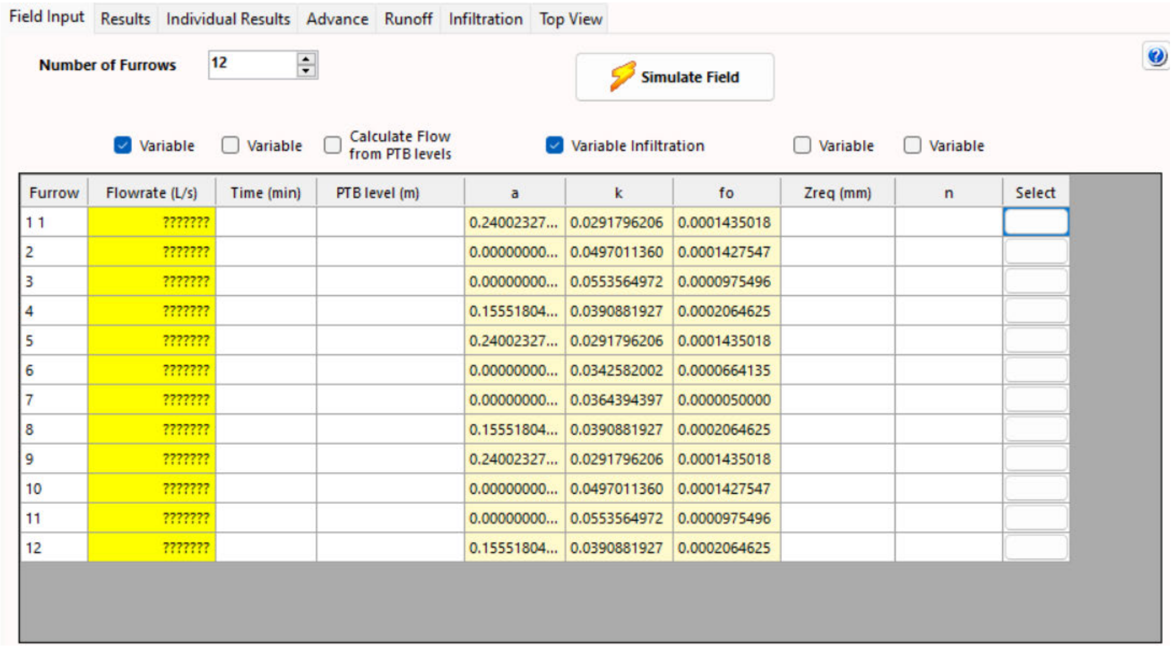


Figure 7.1 Multi furrow input function screen on SISCO advanced software version.

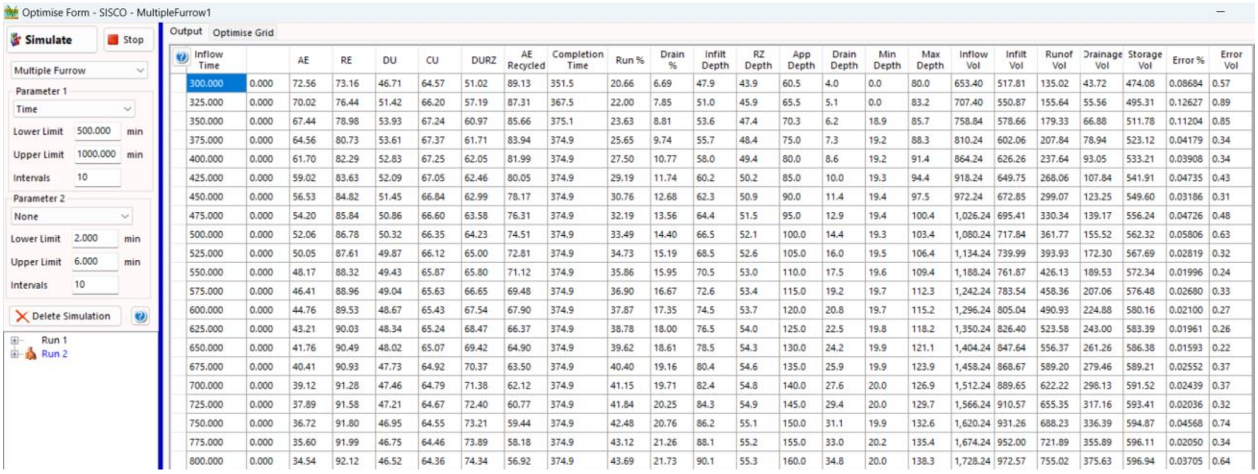


Figure 7.2 Optimisation feature of SISCO advanced version for prompt evaluating of irrigation performance affecting variables.

The optimisation can be carried out either on a single furrow (from the primary input in SISCO) or for multiple furrows simultaneously taken from the multi furrow input. SISCO will simulate the single furrow or the group of furrows for each combination of the optimisation parameters and retain the results. Figure 7.2 presents an example where each line represents the performance of the field at a different inflow rate and inflow time.

7.2 STRUANVILLE FARMING CO. CHOSEN FLOWRATE AND DURATION

This section is aimed at evaluating the irrigation event that was originally proposed by the Struanville Farming Co management. Whilst data was collected from an irrigation event in the above chapter, it is important to understand what the performance would have been like if the event went entirely as planned. In particular there was a large decline in hydraulic head which ultimately reduced the flow rate in the middle of the irrigation consequently affecting the irrigation for better and worse. Through communicating with management, it was determined that the irrigation was intended to start around 6:30am and conclude at 5:00pm for this specific field. It was observed that the starting hydraulic head was in the range of 230-250mm thus it was decided that to assume a hydraulic head of 240mm. This translated to an irrigation event that lasted 630 minutes with a constant flow rate of 2.903 L/s. Given the labour and setup requirements it is difficult to manage an irrigation system to fulfil these intended requirements as determined by the data recorded, however this section provides an overview on what the irrigation performance would have been like if executed as designed by the farm.

The analysis results are depicted in the figures below, with the advance trajectories plotted in figure 7.3. Similar to the results from chapter 6 individual furrow analysis there is a major difference in the advance movement dependant on the level of compaction. The advance is however reduced dramatically for the normal furrows which sees water reach the end in only approximately 390 minutes compared to the 660 minutes. This is ultimately a result of the higher flow rate remaining constant throughout the entire duration of the event. As forecast the higher compaction furrows yield a lower advance trajectory, even more so with this constant 2.903 L/s flow rate.

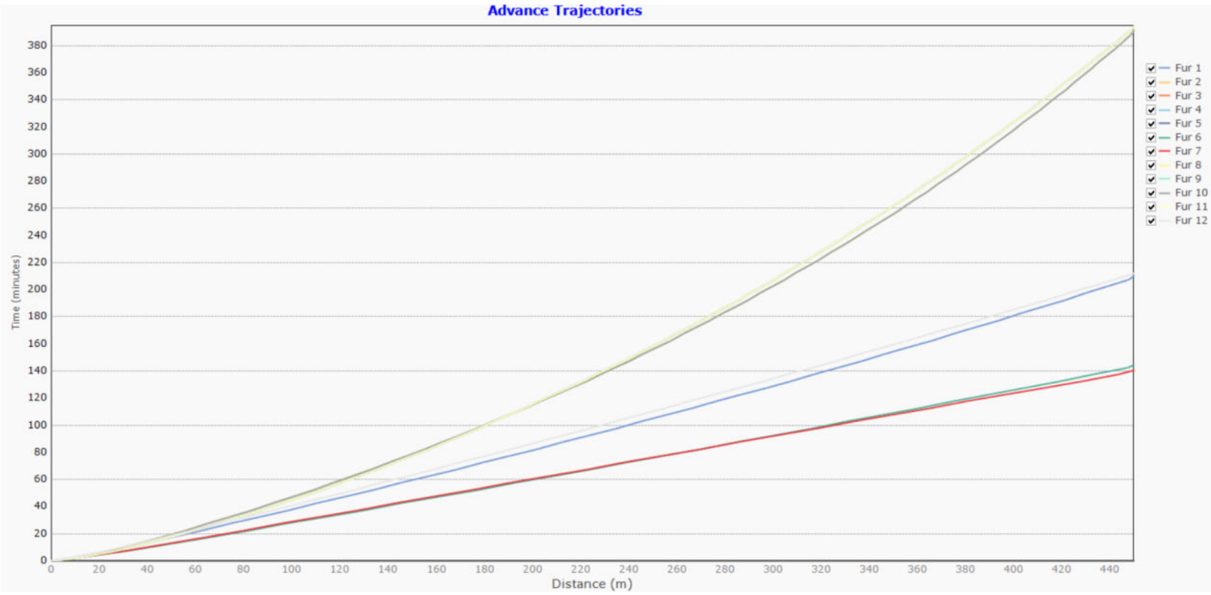


Figure 7.3 SISCO multiple furrow advance trajectories for 12 furrows according to the farm proposed irrigation.

Runoff was a more prominent issue with the farms intended irrigation plan, with figure 7.4 below illustrating the runoff observed from each of the 12 rows. It is observed that the tramline furrows labelled as furrow number 6 and 7 record the highest runoff with the planting tracks in furrow 1 and 12 also having significant runoff. Generally, the tramlines recorded runoff around 70 to 95 m^3 suggesting that the intended plan would have had more wastage than the actual event. This is relatively inefficient as the planting tracks also had values around the 50 to 60 m^3 range. On a different note, the runoff for normal furrows was higher at 15 m^3 than the field trial data which was barely able to reach the end of the furrow. Ultimately there is a major inconsistency in terms runoff, with the intended irrigation plan yielding more wastage in runoff than the real event data.

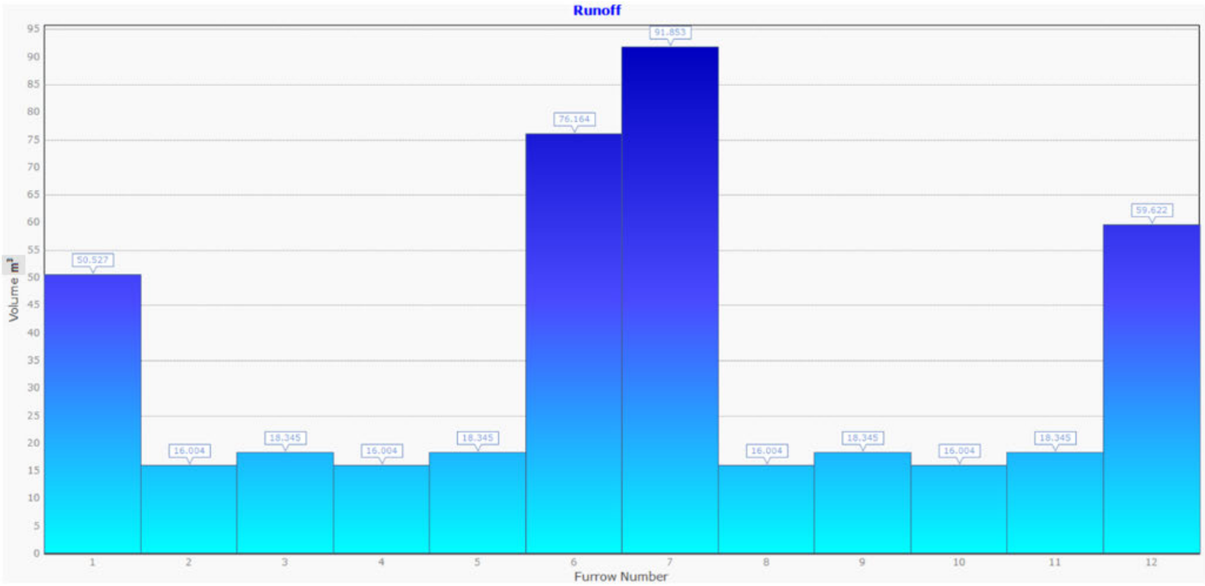


Figure 7.4 Calculated runoff for each furrow across 12 furrows for the farm proposed irrigation

The infiltration from the farm proposed irrigation event is plotted below in figure 7.5. The results remain relatively similar particularly for the compacted trials but there is still a major change for the normal uncompacted furrows. The tramlines despite receiving significantly more water from this irritation only record similar infiltration. This is due to the soil compaction reducing the amount of water that the soil can hold, altering the saturation point at which it cannot infiltrate any more water during that event. The planting furrows yielded similar results with compaction reducing infiltration however they were still able to have enough water to meet the requirement. The major difference in the normal furrows compared to the results observed from the trial data is the increased distribution uniformity. Whilst it starts relatively high around 115mm to 120mm it only drops to about 77mm. This is significantly different to compared to the 0mm and 35mm minimum that was recorded from the trial data of row 3 and 4. This ultimately means that this constant flowrate would be a beneficial factor for the uncompacted furrows however the predetermined cut off time is excessive causing too much infiltration for the actual crops to utilise.

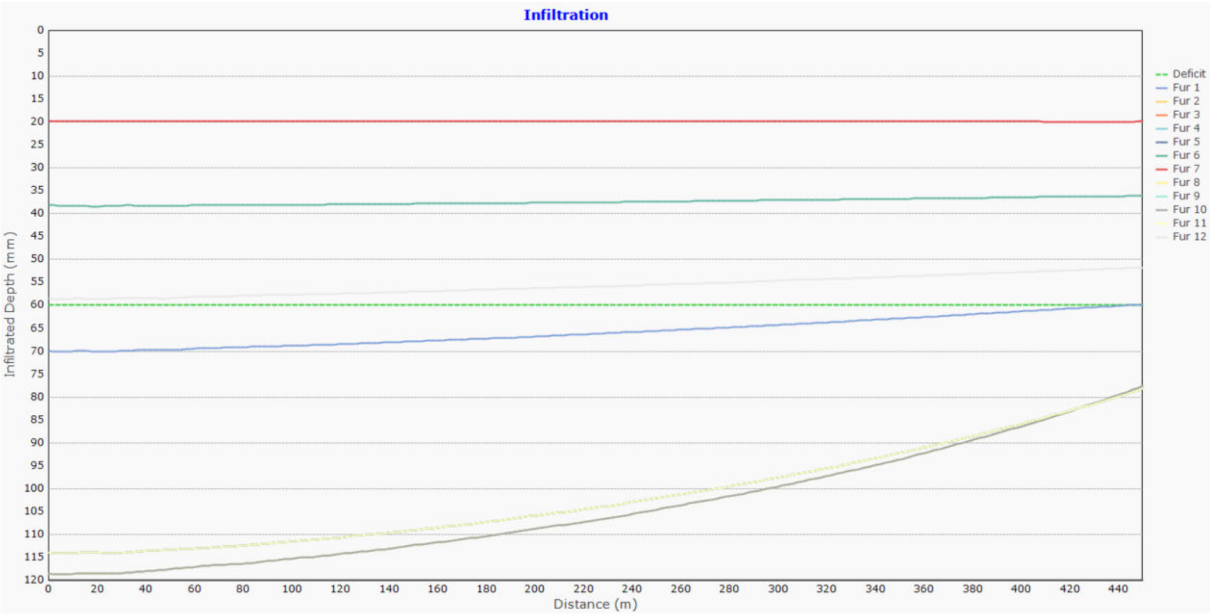


Figure 7.5 Simulated infiltration for the farms proposed irrigation schedule across 12 furrows.

The multi furrow analysis in SISCO allows for a visual plot of the field furrows with figure 7.6 below illustrating how much of the field actually fulfilled the 60mm requirement in the root zone. The best case scenario would be to see the entire field blue however this has been proven to be nearly impossible with the compaction from tramlines allowing maximum infiltration values of between 20mm to 40mm. Whilst this irrigation is still exceedingly beneficial at meeting majority of the crops water requirement it has been proven that a lot of wastage has occurred in deep percolation and runoff for this to occur. This denotes that the farm chosen flow rate and duration should satisfy crop requirements but is going to have a poorer application efficiency and higher labour requirements.

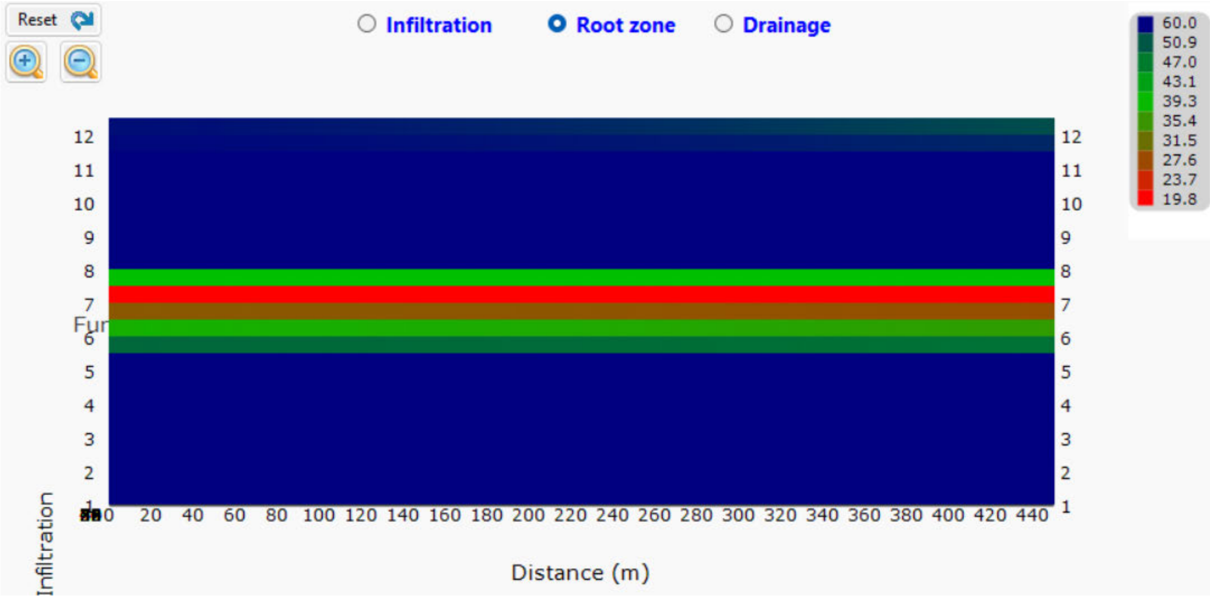


Figure 7.6 Top view of infiltration into the required root zone (60mm) for the 12 furrows along the length of the field according to farms proposed irrigation plan.

The final aspect from all of the above figures is to produce a series of results that can be used to evaluate the successfulness and efficiency of the operation. Figure 7.7 below demonstrates the results for the farmer specific flow rate and duration. The first major aspect to note is the low application efficiency of 44.60%. This is extremely low and is a result of the over application of water to the field, this is exemplified as the average depth is 83.46mm significantly higher than the 60mm requirement. It also suggests that 1.317 ML are used for the irrigation of just 12 furrows much of which is being lost in runoff recycling and deep percolation. The beneficial aspect as referred to before is the requirement efficiency of 90.68% which suggests that the application will still result in a maximised crop yield. The important question for the farmer to consider is where there are changes that can be made to both maximise crop yield and to increase the efficiency of the irrigation.

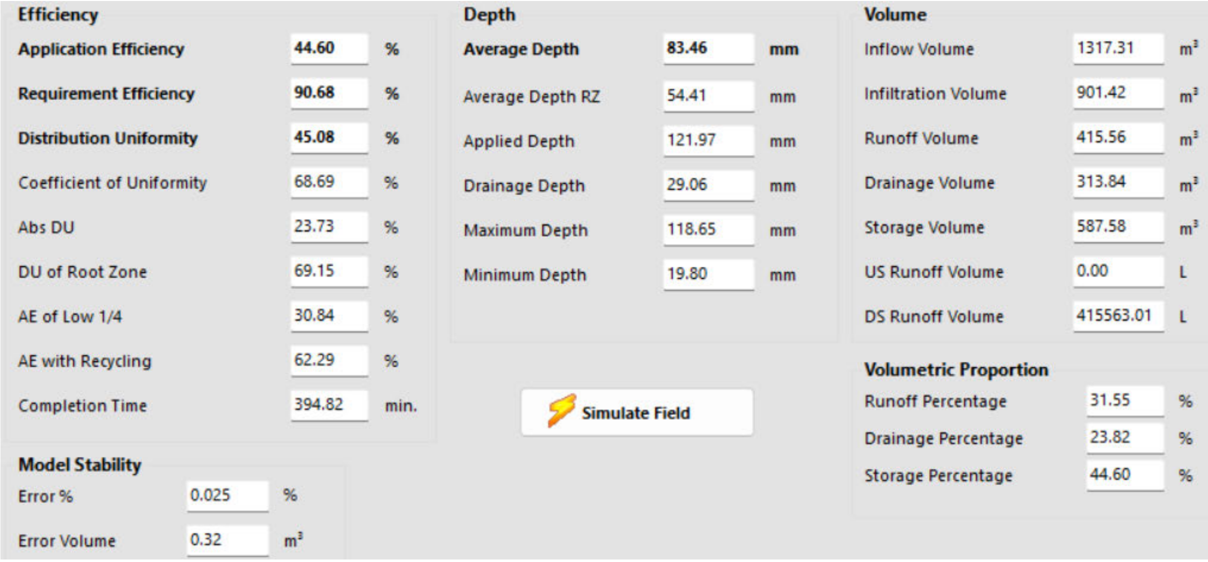


Figure 7.7 Collective results summary from SISCO for 12 furrows according to the farm proposed irrigation.

7.3 OPTIMISED EVENT DURATION FOR CONSTANT FLOWRATE

The next strategy involves no adaptations to Struanville Farm proposed flow rate however utilising SISCO optimise feature to find the best cut off time. As mentioned, the assumed continuous flow rate is 2.903 L/s which suggests the head ditch has a constant hydraulic head of 240mm. Through the software optimisation it was recommended that the duration of the irrigation lasts for around 385 minutes. This value is significantly less than the current irrigation plan at struanville farm and is aimed at reducing the amount of wastage and maintaining the high yield. Figure 7.8 portrays the advance trajectory for this irrigation plan and given that it has no alterations to the flowrate it yields the exact same results as figure 7.3 from the above section. As recalled the lower compaction furrows advance takes longer to reach the end than the higher compaction trials. Overall, the advance is still much quicker than the collected data which suggested the normal furrows could take up to 660 minutes to advance to the end.

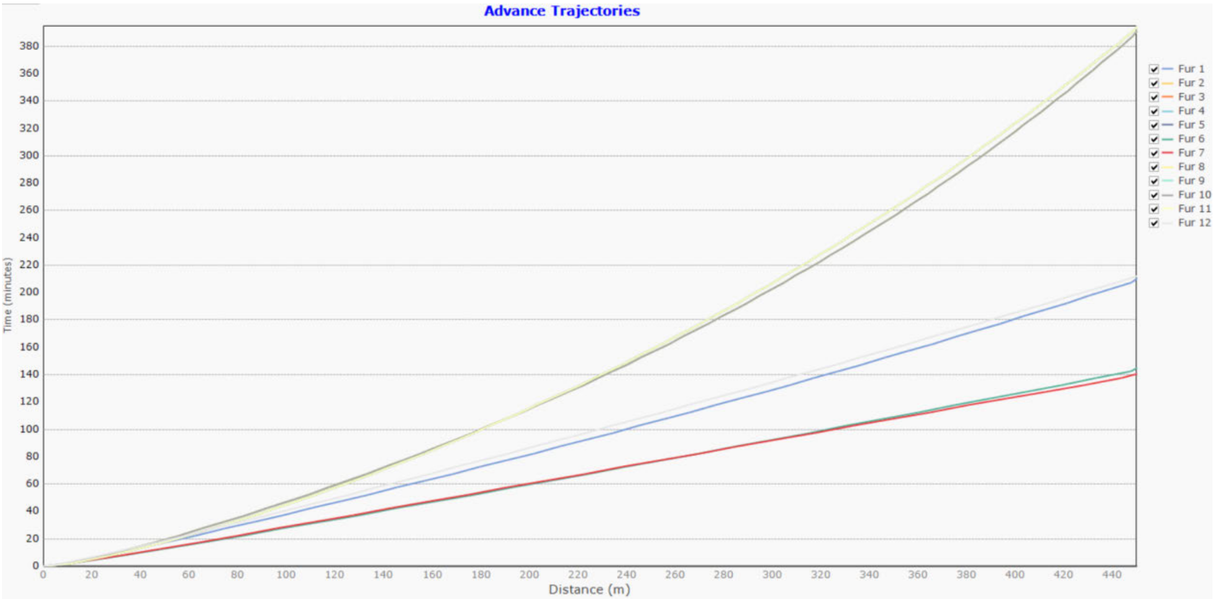


Figure 7.8 Advance trajectories from SISCO multiple furrow analysis for constant flow rate with optimised time to cutoff.

The runoff chart also illustrates a very similar pattern to that of which was illustrated in section 7.2 of the report. This is a result of increased runoff in the tramline furrows in the middle and on the outside where there is a planting track furrow as per figure 7.9 below. The main difference lays in the actual volume of runoff projected with the runoff in the tramline expected to be between 40 and 50 m^3, just over half what was recorded in the prior simulation. Furthermore, the planting tracks only record values of 23.6 and 27.7 m^3 which is also approximately 50% of the farm chosen irrigation cut off time. The normal furrows also experience this effect with figure 7.9 suggesting just over 1 m^3 in runoff from the trails. Thus it can be assumed that the reduced duration for irrigation will reduce runoff and in turn increase the efficiency of the event.

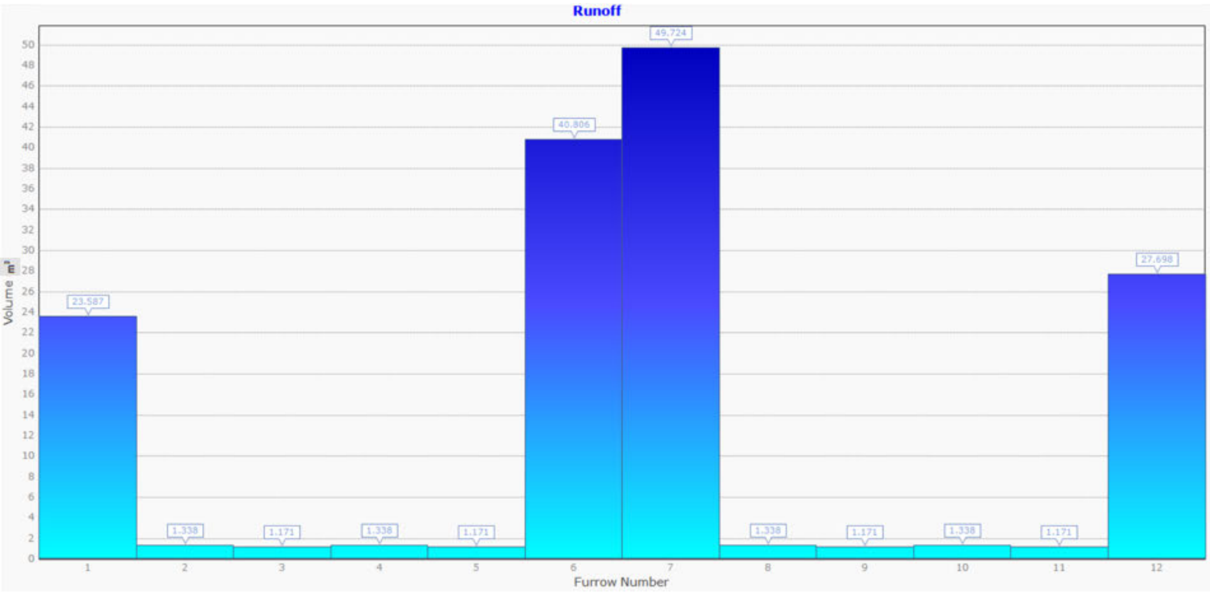


Figure 7.9 Projected runoff per furrow from SISCO multiple furrow analysis for constant flow rate with optimised time to cutoff.

Figure 7.10 below displays the infiltration for this irrigation proposal with a few differing characteristics with the general consensus revealing slightly less infiltration across all furrows. There appears to be similar infiltration in the tramline furrows with the reduce time to cutoff however this is expected from the derived infiltration characteristics that despite additional time no more water will penetrate. One of the major differences is the decrease in infiltration in the normal furrows. In comparison the infiltration for this strategy maximum is around 90mm which means there is less wastage than the farm irrigation design. There does appear to be a decline at the end of the normal furrows towards the 360m mark where infiltration drops below 60mm to a minimum of about 40mm. This is aimed at reducing deep percolation in the uncompacted furrows but still ensuring there is sufficient water to maintain a high yielding crop.

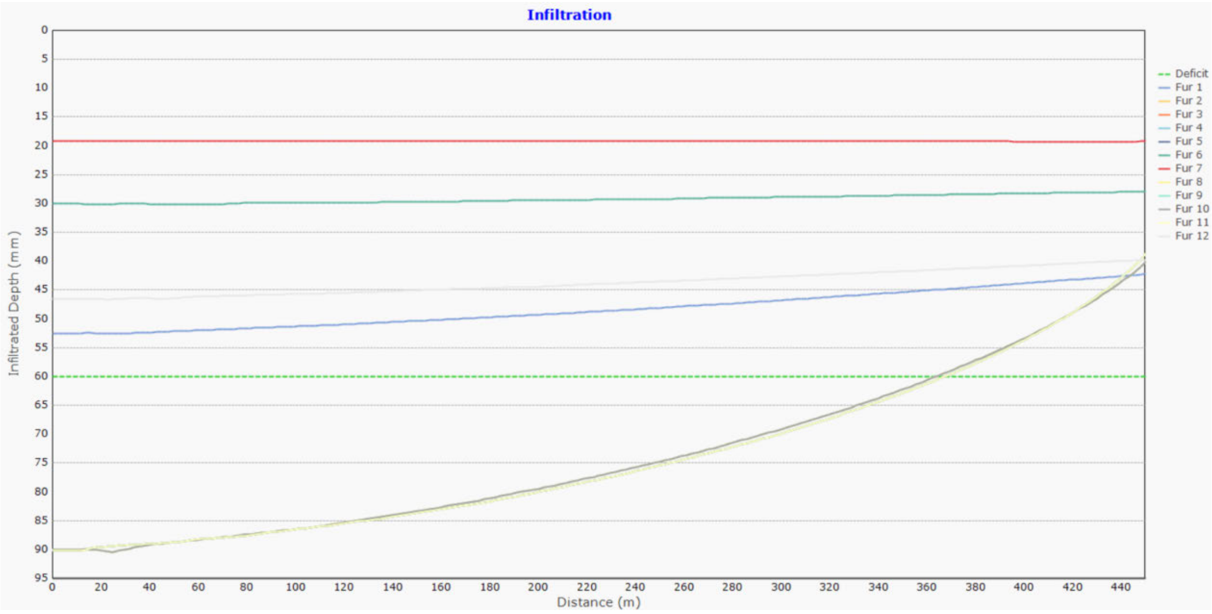


Figure 7.10 Predicted infiltration from SISCO multiple furrow analysis for constant flow rate with optimised time to cutoff for each furrow.

Utilising the infiltration information above a birds eye view plot of the field is presented by SISCO illustrating the rootzone infiltration in particular. This is picture in figure 7.11 below with it assumed that infiltration greater than 60mm will be lost into deep water storage. As can be seen the majority of the field is blue and receiving above the requirement, however there is still some red which is depicted in the area of the tramline furrows. A contributing difference in this proposal is greener in the planting furrows along the edge and also at the end of the furrow. The reduced duration appears to have leave these parts of the field with around 45mm of infiltration. This is not ideal however throughout implementing this change to irrigation duration, it is aimed at increasing the overall efficiency of the operation.

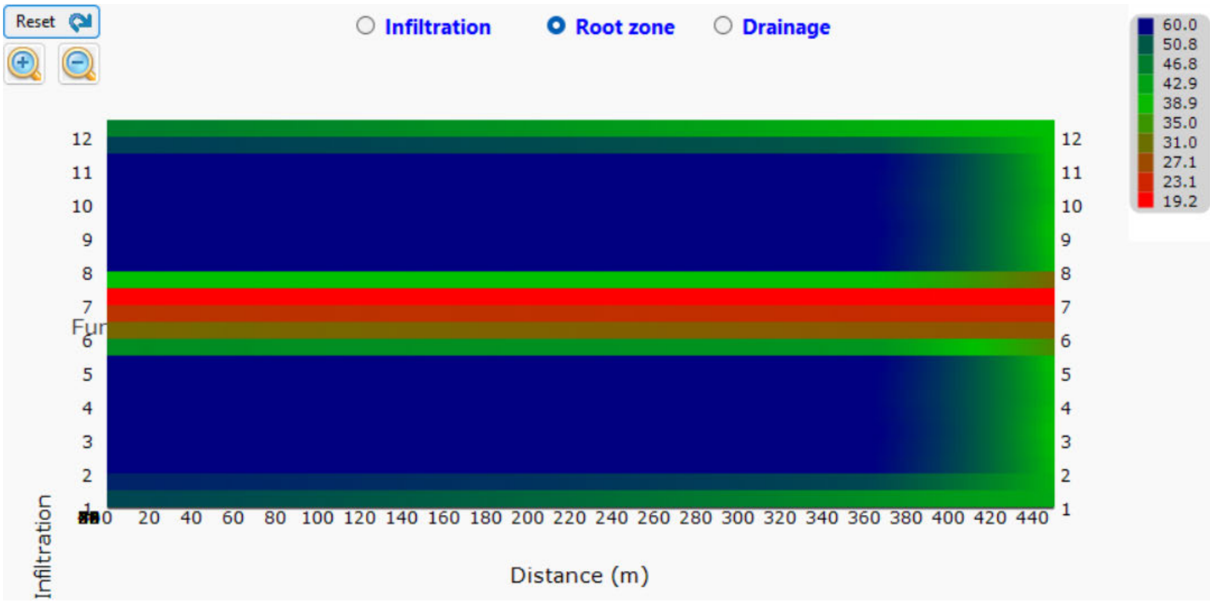


Figure 7.11 Depiction of furrow water infiltration requirement in the root zone (60mm) over the length of field with optimised cut off time.

As referred to this strategy is aimed at improving efficiency whilst still maintaining the quality of the crop. With reference to the results summary from SISCO in figure 7.12 below, it appears to be a more well-rounded irrigation event that can satisfy both of these criteria's. The most important aspect is a jump to 67.36% in irrigation efficiency with an average infiltration depth across of the field of 61mm. This promotes the irrigation to be in the upper half of surface irrigation system efficiency throughout Australia, just through optimising the time to cutoff. This is largely due to the reduction to overall inflow volume for the 12 furrows to 0.811 ML, with only 0.151 ML going to runoff contributing to only 18.72% in runoff. This is a massive improvement to efficiency despite the requirement efficiency value only dropping by an approximate 6%. Overall, this irrigation proposal will yield greater productivity benefits by reducing water usage, labour requirements and time wastage whilst maintaining high yields.

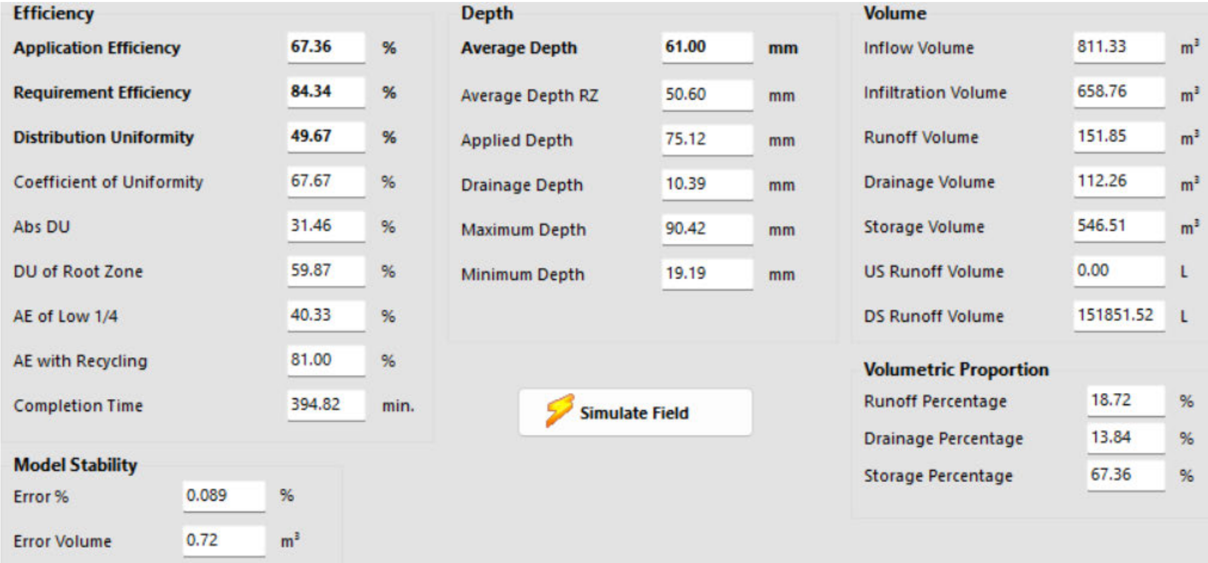


Figure 7.12 Summary of results from SISCO multiple furrow analysis for constant flow rate with optimised time to cutoff.

7.4 OPTIMISED FLOWRATE AND DURATION

The last of the proposed irrigation plans includes optimising both the flowrate and the duration of the event. This is aimed at improving the efficiency of the entire operation and sustaining the corn crop simultaneously. Unlike the previous 2 strategies this will involve making adaptations to the siphon sizes to manipulate the flowrate dependant on the level of compaction in that furrow. Whilst there are countless changes that can be made to optimise the entire process, this strategy is still designed to be both cost effective and practical for implementation, a crucial aspect for farmers who are considering these changes.

Through the SISCO multi furrow analysis and optimising software alongside the Cotton Info toolbox 7 (Wigginton, 2020) the following proposal was developed. The toolbox contains a table that provides a theoretical calculated flowrate from the operating head value for common size siphons. This information was accessed with the optimising feature to find the best most practical flow rates for each furrow as laid out in figure 7.14. The length of siphon was chosen kept the same at 4m as it may be the most suitable to the physical setup of the head ditch at Struanville farm. The remaining details for each of the furrows are outlined below with a constant operating head requirement of 280mm chosen:

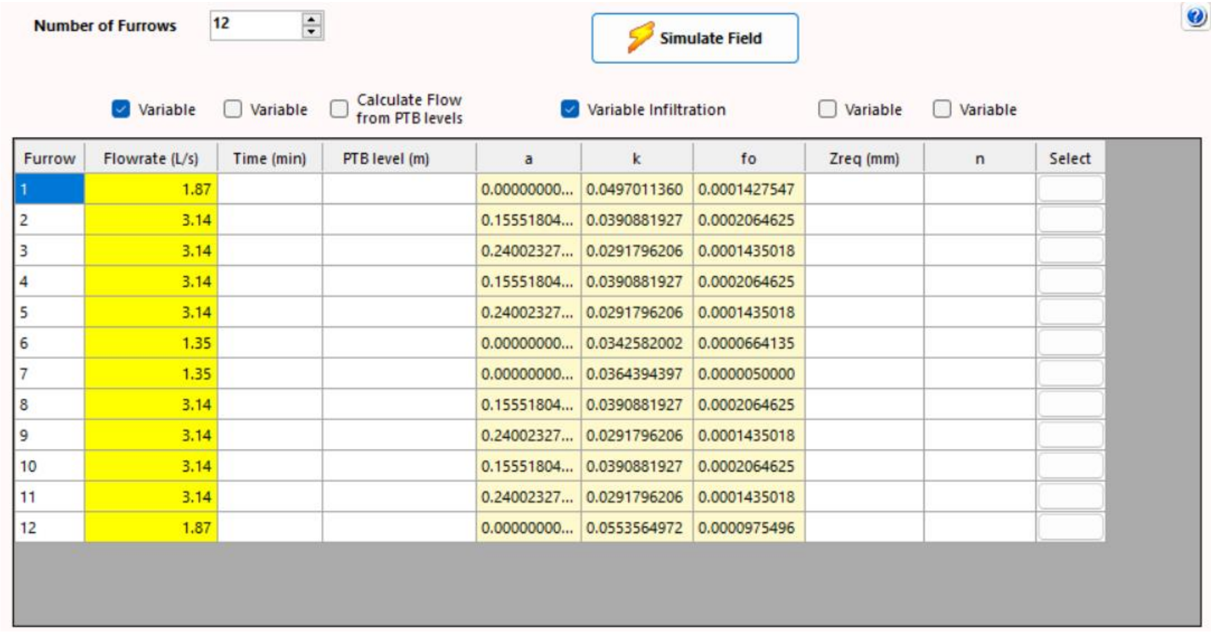
- Tramline Furrows – 1.35L/s using 1 ½” Nominal Size, 38.1mm ID
- Normal/Uncompacted Furrows – 3.14L/s using 63mm Nominal Size, 55.5mm ID (Current Size)
- Planting Track Furrows – 1.87L/s using 50mm Nominal Size, 44.0mm ID

These are the outlined requirements for the optimising the flow rate with 65 siphons required for tramlines and an additional 65 for planting track furrows assuming a field with 390 furrows. It ultimately means that there will need to be 260 siphons of this size for the normal furrows. This is not going to be a major issue as the design chosen utilises the preexisting siphon dimensions to ensure input costs are not too excessive. The actual duration of the event was found using the optimise feature with it being exactly 380 minutes. These values were placed into the multi furrow analysis page of figure 7.14 and the results are expressed throughout the remaining figures in this section.

Flow rate in litres/seconds (L/s), siphon Length = 4.0 metres

Operating head (mm)	Nominal siphon size, internal diameter (mm)							
	1 1/4", 31.75	1 1/2", 38.1	2", 50.85	50 mm, 44.0	50 mm, 47.0	63 mm, 55.5	63 mm, 59.0	75 mm, 65.1
100	0.54	0.81	1.54	1.12	1.30	1.87	2.14	2.66
120	0.59	0.89	1.69	1.23	1.42	2.05	2.35	2.92
140	0.63	0.96	1.83	1.32	1.53	2.22	2.54	3.15
160	0.68	1.02	1.95	1.41	1.64	2.37	2.71	3.37
180	0.72	1.09	2.07	1.50	1.74	2.51	2.88	3.57
200	0.76	1.14	2.18	1.58	1.83	2.65	3.03	3.76
220	0.79	1.20	2.29	1.66	1.92	2.78	3.18	3.95
240	0.83	1.25	2.39	1.73	2.01	2.90	3.32	4.12
260	0.86	1.30	2.49	1.80	2.09	3.02	3.46	4.29
280	0.90	1.35	2.58	1.87	2.17	3.14	3.59	4.45
300	0.93	1.40	2.67	1.94	2.24	3.25	3.71	4.61
320	0.96	1.45	2.76	2.00	2.32	3.35	3.84	4.76
340	0.99	1.49	2.85	2.06	2.39	3.46	3.95	4.91
360	1.02	1.54	2.93	2.12	2.46	3.56	4.07	5.05
380	1.04	1.58	3.01	2.18	2.53	3.65	4.18	5.19
400	1.07	1.62	3.09	2.24	2.59	3.75	4.29	5.32

Figure 7.13 CottonInfo toolbox 7 providing theoretical flow rates for commonly used siphon dimensions (Wigginton, 2020).



Furrow	Flowrate (L/s)	Time (min)	PTB level (m)	a	k	fo	Zreq (mm)	n	Select
1	1.87			0.00000000...	0.0497011360	0.0001427547			
2	3.14			0.15551804...	0.0390881927	0.0002064625			
3	3.14			0.24002327...	0.0291796206	0.0001435018			
4	3.14			0.15551804...	0.0390881927	0.0002064625			
5	3.14			0.24002327...	0.0291796206	0.0001435018			
6	1.35			0.00000000...	0.0342582002	0.0000664135			
7	1.35			0.00000000...	0.0364394397	0.0000050000			
8	3.14			0.15551804...	0.0390881927	0.0002064625			
9	3.14			0.24002327...	0.0291796206	0.0001435018			
10	3.14			0.15551804...	0.0390881927	0.0002064625			
11	3.14			0.24002327...	0.0291796206	0.0001435018			
12	1.87			0.00000000...	0.0553564972	0.0000975496			

Figure 7.14 Optimised flowrate values dependant on the status of each furrow in accordance with calculated data for multiple furrow analysis in SISCO.

The ability to change the flowrate greatly impacts the speed of the trajectory. The optimised irrigation design involves ensuring that each furrow is reaching the end of the field around the same time. As depicted in figure 7.15 below, the advance trajectories are much closer than the previous strategies, to a point where all furrows should have water at the end between 260 and 350 minutes. This allows for more uniformity across the entire irrigation and improves the likelihood of infiltration particularly in the compacted furrows. Whilst the tramlines still have the fastest flowing furrows, it has slowed down dramatically by over 100 minutes. From the other perspective, normal furrows have got significantly faster with the aim to produce more even infiltration and allowing them to all finish around similar times.

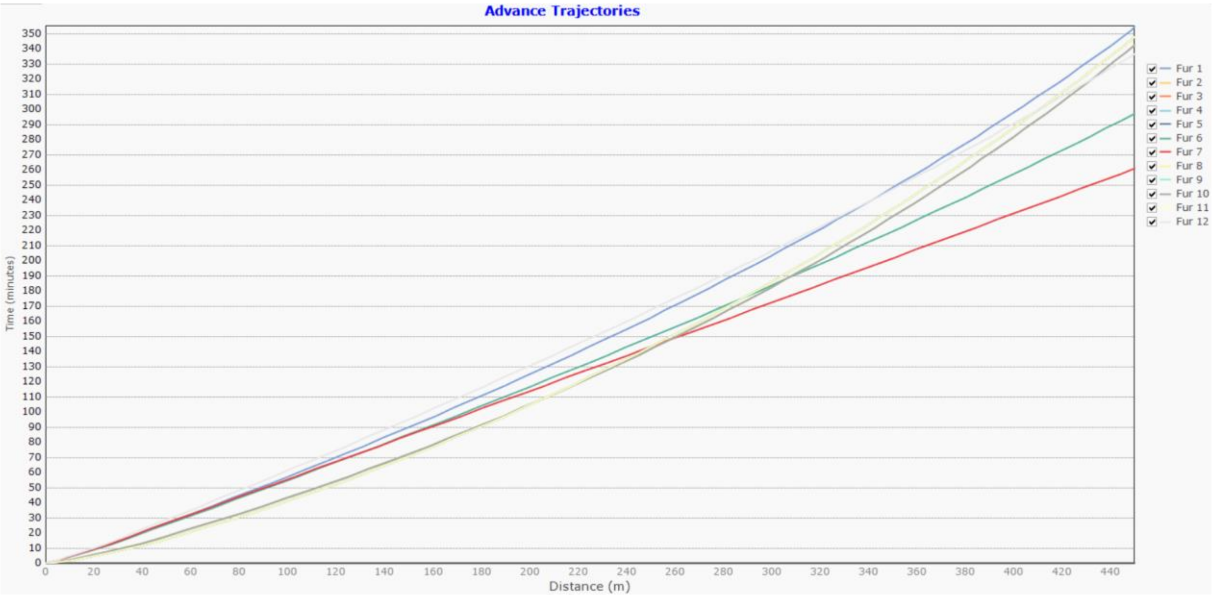


Figure 7.15 Advance trajectory from SISCO multiple furrow analysis for optimised flow rate and irrigation duration.

The next important aspect of the optimised strategy is to control the length of the irrigation to reduce runoff. The below figure (7.16) is a substantial improvement to the other plans with more consistency across all furrows despite the level of compaction. It is noted that there is still a slight height difference in the tramlines of furrows 6 and 7 however the predicted runoff only ranges from 3 to 14 m^3. This is a great improvement to the overall uniformity with the planting track and normal furrows experiencing very similar values also. This ultimately denotes that the new flowrate and duration is beneficial at reducing the wastage from runoff and in turn decrease labour and energy requirements for recycling this water.

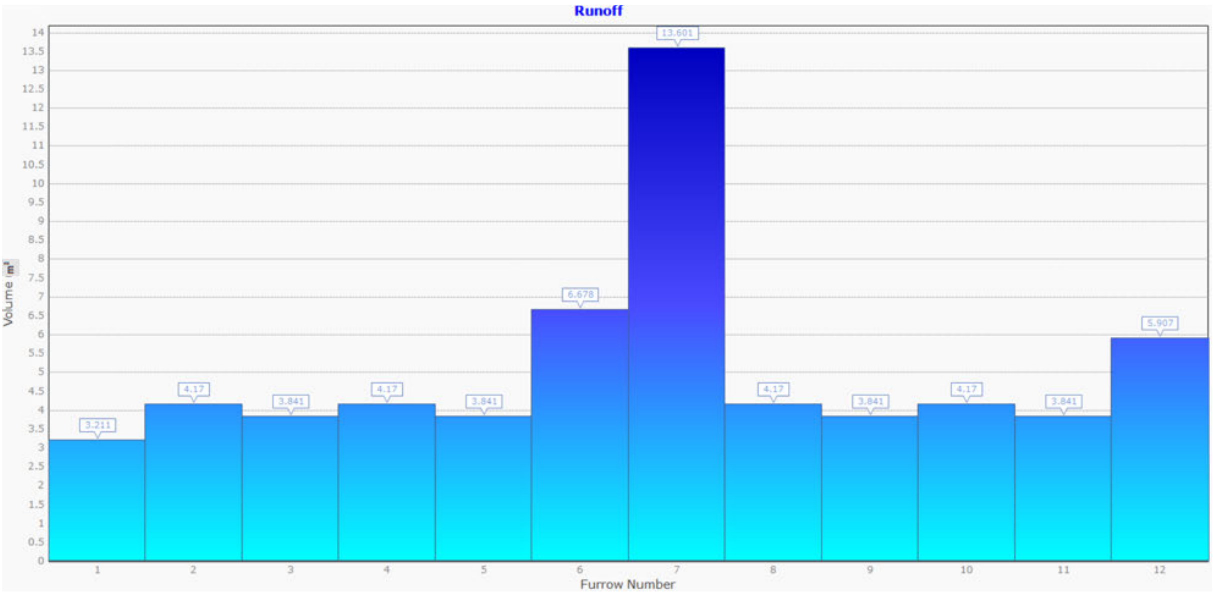


Figure 7.16 Predicted runoff per furrow from SISCO multiple furrow analysis for optimised flow rate and irrigation duration.

The chosen flow rate and duration is aimed at maximising the infiltration, but also in reducing the waste through deep drainage. As per figure 7.17 the infiltration remains relatively similar for tramline furrows (6 & 7) particularly as the research data suggests that the soil will struggle to infiltrate more water than 20 to 30mm. The planting furrows still do meet the minimum requirement however given that the compacted furrows only account for 4 out of the 12 furrows in the field pattern, it is more important to consider the normal furrows. The altered flowrate has allowed for greater uniformity in the 8 normal furrows with a maximum of 90mm and a minimum of around 50mm. This new strategy means that less water is going to be lost to deep percolation and thus more readily available for the corn plant.

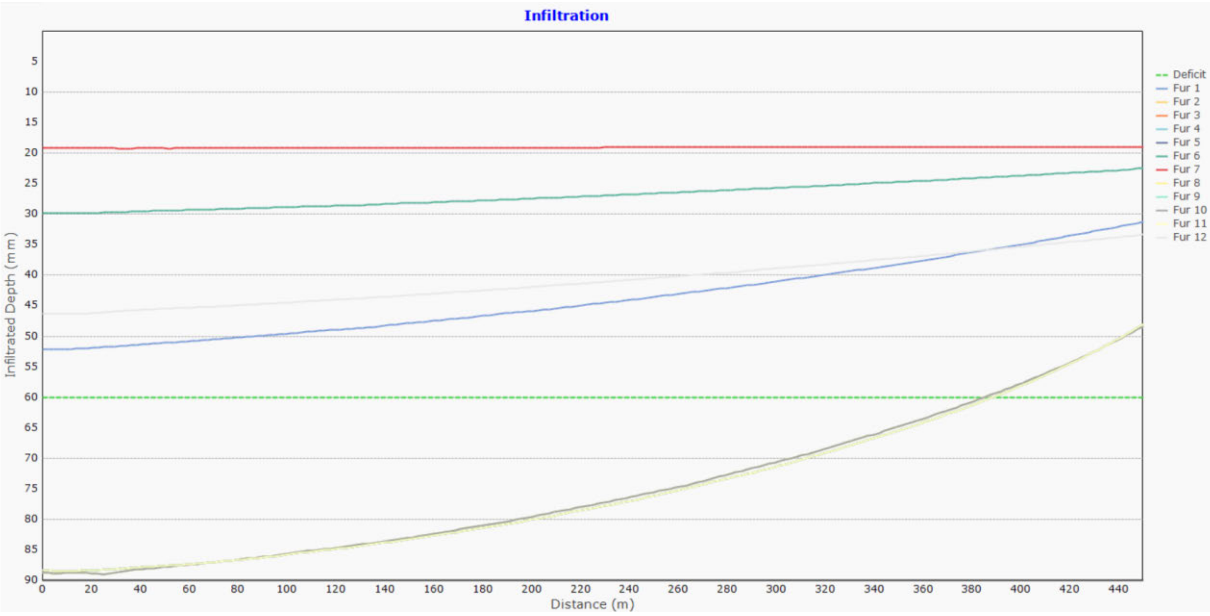


Figure 7.17 Forecasted infiltration from SISCO multiple furrow analysis for optimised flow rate and irrigation duration.

As mentioned above one of the main goals for the irrigation is to supply the crop with enough moisture to maximise its growth and yielding potential. The figure below (7.18) is a plot of the 12 furrows and represents the amount of infiltration that has going into the root zone. It illustrates very similar characteristics to the strategy from above with the slight exception of more green observed in the planting furrows. There does however appear to be a slight increase in the coverage of the normal furrows with less green at the end of the field. This is an important aspect when the uncompacted furrows contribute for 66.67% of the entire field. The overall consensus reveals that the field is still getting the required 60mm and therefore should not be affecting the yield notably, if at all.

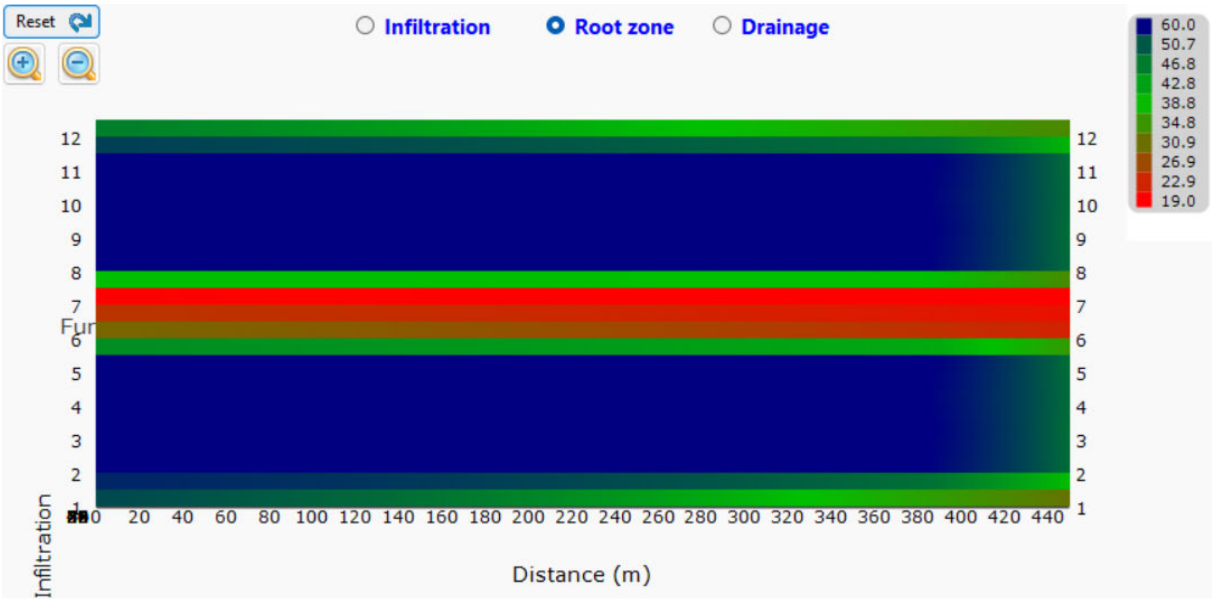


Figure 7.18 Visual plot of infiltration requirement in the root zone (60mm) over the length of the field.

The final component of the optimised irrigation plan is to evaluate the results which SISCO has presented in figure 7.19 below. As expected, the customised flow rate for different levels of compaction with an optimised duration has the highest application efficiency of 75.57%. This is a value not observed very often throughout surface irrigation in Australian agricultural. Some of the other important aspects is that it can achieve this application efficiency whilst still having an average infiltration depth of 60.91mm. This is still able to satisfy the requirement of 83.92% of the entire field. The other major component is the inflow volume which has been reduced to only 0.719 ML across the 12 furrows analysed. This value is significantly better with the collective runoff volume only 0.061 ML which equates to roughly 8.5% of the applied volume. Ultimately this proposed irrigation would be the most effective and efficient providing benefits to both the crop and farm management.

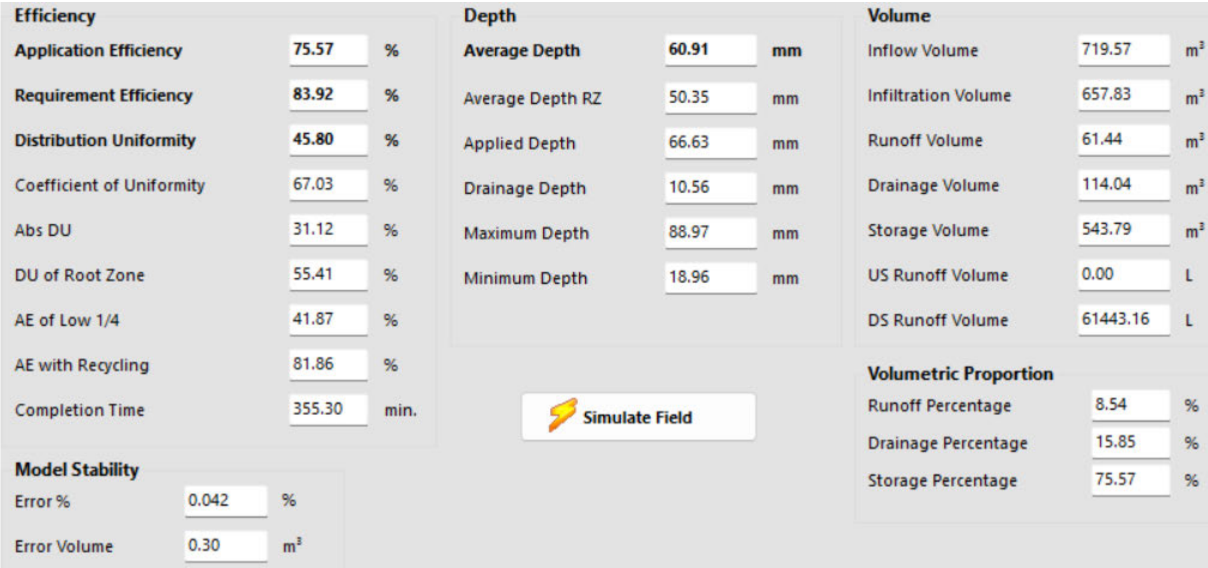


Figure 7.19 Summary of results from SISCO multiple furrow analysis for optimised flow rate and irrigation duration.

7.5 COMPARISON OF STRATEGIES

This chapter has introduced and completed three irrigation simulations utilising multi-furrow analysis. They included a farm chosen flow rate and duration, an optimised cutoff time with constant flow and finally an optimised flow rate and duration. There have been many beneficial aspects for each of the design however the below table (7.1) compares the key parameters to the actual irrigation event from chapter 6. The first notable aspect is considering the application efficiency, where the recorded irrigation event actually yielded approximately 10% better than the farm specific irrigation proposal (1). The table does however reveal that the 2nd and 3rd irrigation proposals have a dramatic improvement to the application efficiency with 67.36% and 75.57% respectively. The requirement efficiency across the recorded data and irrigation proposals remain in similar range of between 83% and 91%. This is one of the most important values as it suggests that the greater part of the field will receive enough water to maximise the corn crop yield. The recorded event and irrigation proposal 1 by the farm experience the highest requirement efficiency which may be a result of the higher average infiltration. It is expected that the field average would be 79.57mm in the recorded event and 83.46mm in the farm specific design (1). This is beneficial for the crop as it still receives enough water however there is more loss through ground drainage which can be costly and wasteful for farmers. As seen the drainage for the recorded irrigation and proposal 1 is significantly higher than the optimised strategies of 2 and 3. As a result the average infiltration is around 61mm for both the 2nd and 3rd proposal as SISCO has optimised the irrigation event to reduce any deep percolation. Furthermore, the runoff volume is dramatically reduced with the 3rd proposal with optimised duration and flow rate only experiencing 2 ML of runoff. Ultimately SISCO has been able to quantify and compare irrigation events, assessing the efficiency of the entire of field to determine which strategy will have the most valuable results.

Table 7.1 Comparison using SISCO software of recorded irrigation event against alternative irrigation proposals/strategies.

	Application Efficiency (%)	Requirement Efficiency (%)	Distribution Uniformity (%)	Average Infiltration (mm)	Inflow Volume (ML)	Runoff Volume (ML)	Drainage Volume (ML)
Recorded Irrigation	54.58	88.31	75.90	79.57	34.05	6.10	7.04
Irrigation Proposal 1	44.60	90.68	45.08	83.46	42.81	13.51	10.20
Irrigation Proposal 2	67.36	84.34	49.67	61.00	26.37	4.94	3.65
Irrigation Proposal 3	75.57	83.92	45.8	60.91	23.39	2.00	3.71

The comparison completed above has clearly revealed that using SISCO optimisation software can be beneficial at selecting the most productive and efficient irrigation strategy. One factor that is not addressed is the actual investment requirements to implement a new strategy. The third irrigation proposal whilst the most efficient requires purchasing of different siphon sizes and additional labour requirements to set out the siphons in the specific order. This is still a better idea than the recorded irrigation and proposal 1 which take significantly longer to complete the irrigation and require additional labour to supervise the event. The second irrigation proposal yields significantly improved efficiency results by optimising the time to cut off however it does not change the flow rate and thus requires no additional investment. Utilising the siphons that are already in usage but optimising the duration can save an additional 3 or more hours compared to the farms recommended irrigation time. This is an important aspect to consider given that the farmers goal is to produce a high yielding crop with the least amount of input costs.

One of the final aspects to be considered is the design of the head ditch as a pump or gate will need to meet different specifications for each strategy. This is an important issue as the actual irrigation event appeared to have a large reduction in hydraulic head when extra siphons were started ultimately concluding that the system was unable to keep up. Calculations have revealed the constant flow rate in proposal 1 and 2 will demand 25.12 L/s for just 12 furrows to be flowing and this values jumps to 31.56 L/s for the third optimised flow rate proposal. This will ultimately be a decision influenced by a potential cost benefit analysis to reveal the positive and negative impacts of each proposal.

7.6 EVALUATION OF PLANS

Overall, this chapter has analysed 3 different irrigation strategies that quantify the true effects of compaction in furrows. Figure 7.20 below is a SISCO generated root one infiltration plot for one quarter of the entire field using the optimised flowrate and duration proposal. This was completed by adding furrows with the same 12 furrow pattern to repeatedly to reveal the infiltration that is occurring in the root zone in larger portion of the field. This is the using the same pattern that was observed in figure 6.26 from chapter 6. As seen the red areas are representative of the tramlines where compaction is reducing the level of infiltration, and the green runs are illustrating where the planting tracks are also affected by compaction. The blue sections show were the required 60mm of infiltration has occurred and it generally appears in the normal uncompacted furrows. The overwhelming data reveals that compaction has a major impact on irrigation infiltration and efficiency. This chapter has successfully introduced a proposal that incorporates the preexisting farm setup with a SISCO optimised duration to improve the water efficiency, reduce labour requirements and maintain high yields. The final proposal also confirmed the maximum practical irrigation efficiency accounting for the different compaction throughout the field in the form of variable flow rates. Ultimately it has proven that SISCO has been able to effectively identify the variability in field compaction and create enhanced irrigation proposals that can factor in this compaction.

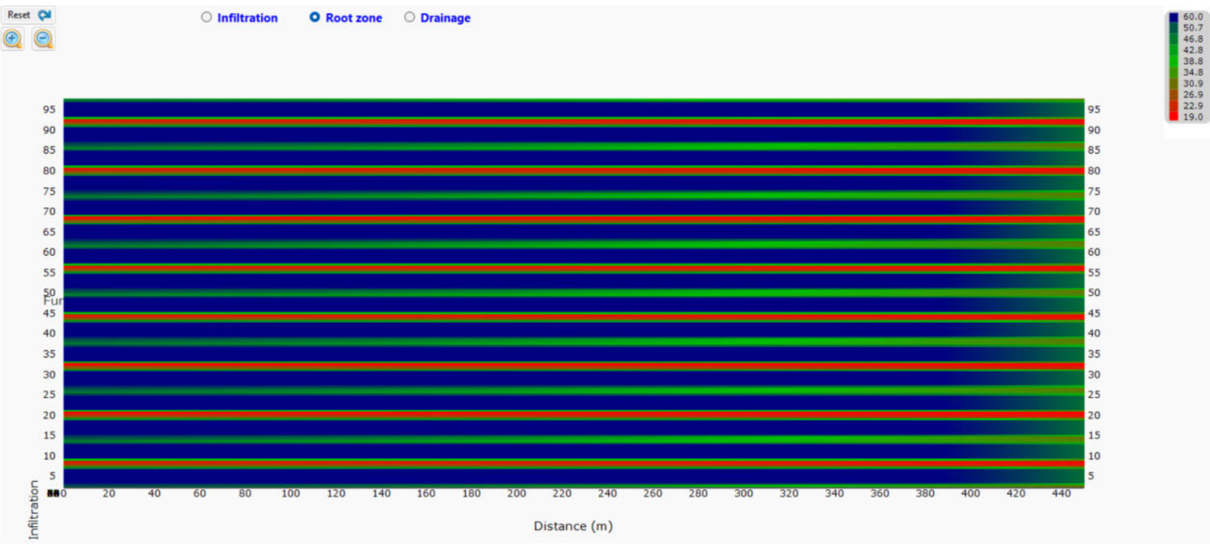


Figure 7.20 SISCO generated root zone infiltration plot for one quarter of the entire field.

7.7 CONCLUSION

This chapter has successfully introduced and compared strategies that to improve the performance of an irrigation event. It was found that it is in fact possible to optimise a set of furrows that have different compaction levels instead of 1 at a time. The prior research found that recommendations to improve irrigation could be made through the use of SISCO. This project however has acknowledged that a plan can be developed to account for the different level of compactions observed in tramlines and planting tracks. The theoretical modelling in SISCO has successfully been able to improve the entire fields irrigation efficiency by more than 20% than the recorded irrigation event. It is able to improve by such as large margin as it factors in the field compaction variability. The 2nd and 3rd strategy both illustrated irrigation performance improvements however optimising flow rate and duration yielded the best results. This was done by making changes to the siphon sizes for compaction furrows to reduce the flow rate. It was proven to have a higher potential application efficiency and reduce both drainage and runoff wastage.

The main goal was to provide recommendations that were both practical and still comparatively cost effective for a farmer to implement. It was found that none of the proposals resulted in a perfect requirement efficiency with it noted that the compacted furrow generally have a low infiltrated depth despite changes to flowrate and duration. Ultimately improving the irrigation efficiency up to 75% as projected by the 3rd strategy is a massive improvement and considered to be high efficiency for surface irrigation.

CHAPTER 8 CONCLUSION

8.1 SUMMARY OF RESEARCH FINDINGS

The research has produced many valuable findings that has great potential to impact Australian and global agricultural production. The project specifications and objectives were outlined with the intention to identify how compaction affects irrigation performance and how it can be optimised. A series of literature review introduced the topics of surface irrigation and field variability factors, alongside irrigation modelling software. After a review it was found that SISCO would be the most suitable and accurate simulating software for usage in this research project.

The integration of SISCO meant that sensors would require construction to measure the movement of the advance wave. With collaboration from the Centre for Agricultural Engineering a predesigned sensor was further developed with a total of 35 sensors being produced for this project. Although the sensors fulfilled the outlined requirements, further research could be completed on reducing the cost and improve the design.

The methodology involved sourcing a willing farm to complete the testing on. Struanville Farming Co were happy to accommodate providing a field that experience variable levels of compaction for testing. The field was analysed and with the sensors distributed evenly along the intended furrows. The methodology also discussed the factors such as ground slope, flow rate and furrow dimensions which required measurement during the irrigation event for later analysis in SISCO.

The raw data was taken from a trial conducted on the 11th of September 2024 and displayed throughout chapter 5. This data was effectively tabulated with some problems and discrepancies discussed throughout. In particular this included the missing data from some sensors, although it was believed to have minimal effect on the accuracy of SISCO simulations later in the report.

This raw data was then processed individually through SISCO software with calibration of infiltration parameters and a simulation of the irrigation event performed on each row. SISCO results came in the form of advance and recession, infiltration and runoff plots. There was also a results summary page which provided valuable information on the performance of that singular furrow. This yielded many variations with it first noted that the higher compacted furrows would result in poorer irrigation performance.

Utilising the infiltration parameters calibrated throughout chapter 6, a multifurrow analysis of 12 furrows could be conducted. The simulation was setup to reflect the entire field pattern in the attempt to evaluate the whole field performance and develop optimised strategy. Chapter 7 investigated 3 strategies including a farm chosen plan, an optimised duration plan and finally an optimised flow rate and duration event. Through a comparison of the results, it was found that there is potential to increase the application efficiency by more than 20% with SISCO optimised duration and flow rate. The plan was aimed at meeting the plant requirements but reducing the water runoff and drainage.

The theoretical results prove that it is possible to factor in variable compaction levels across a field to achieve high application efficiencies of around 75%. It was found that the compaction was a major impactor on the irrigation performance with less compaction trials yielding better infiltration and application efficiency. Although changes to the flow rate were made it was observed that the extremely compacted tramline furrows would not experience much improvement to infiltration and much of the water applied would just run off. Overall, the best solution involved altering the flow rate with siphon sizes to 1.35 L/s for tramlines, 3.14 L/s for normal furrows and finally 1.87 L/s for planting track furrows. This flowrate combined with a duration of 380 minutes was found to improve application efficiency to as high as 75.57%.

8.2 EVALUATION OF PROJECT SUCCESS

The project was successful in completing the outlined objectives and researching the impact of compaction variability on the efficiency of surface irrigation. It involved an in depth review of literature that resulted in understanding the knowledge gap surrounding impact of compaction on irrigation specifically. The literature review also revealed the extremely helpful Surface Irrigation Simulation, Calibration and Optimisation (SISCO) tool. The accuracy was analysed, and the software was further employed for the rest of the project. A series of advance moisture sensors were developed with the assistance of the Centre for Agricultural Engineering at UniSQ to collect data from the field trials. The Struanville Farming Co provided the opportunity to complete this testing during the irrigation of their corn, providing valuable data for SISCO to utilise. The data was first processed using individual furrow analysis particular to calibrate the soil infiltration characteristics and also to evaluate the compaction of each row. The simulation irrigation performances were quantified and compared to provide greater understanding for increasing efficiency. The SISCO multi furrow and optimisation feature was used to test a series of strategies. A comparison was conducted between farm chosen irrigation scheduling and practical optimised strategies to understand how compacted furrows can be accounted for in irrigation. Ultimately there is plenty more research that can be conducted around irrigating fields with variable compaction however this project successfully identified the quantitative effects of compaction on irrigation performance.

8.3 FUTURE IMPROVEMENTS AND RECOMMENDATIONS

As referred to the project was able to complete the original objectives and provide quantifiable evidence of compaction affecting irrigation. There are many future improvements and recommendations that can be made to understand other performance affecting factors and produce well informed strategies to reduce water consumption throughout Australian agriculture. In regard to improvements, investing more research time into gaining a greater understanding of the plant requirements and recycling efficiency of runoff could reduce the number of assumptions made in the SISCO analysis. Furthermore, improvements could be made by ensuring that the hydraulic head remains constant across the entire irrigation event. This means there are potentially small errors made in the recording of individual furrow flow rates, although given the environment was consistent for all test, it is believed that the report has satisfactory accuracy.

There are also many future research recommendations that can be made as a result of this successful project. To further improve the overall accuracy of the conclusion, a series of more tests within the same and different fields would provide more valuable and qualitative data to be used in creating an optimised irrigation plan. An economical and time efficiency analysis could also be conducted to identify whether investing in new siphons and more labour as per the third irrigation plan would save farmers in water usage and recycling costs. this would be of great interest to farmers as they are constantly looking for cost effective and labour reducing solutions. Further work surrounding the analysis of other soil and nutrient related factors that affect irrigation efficiency could be beneficial also. This would improve understanding of what factors can potentially increase soil moisture retention. Finally, in the extended future, there would be great demand for investigating the integration of advance moisture sensors with irrigation optimising software such as SISCO to provide real time optimisation. This could be further used to automate irrigation processes reducing water wastage, labour requirement and nutrient leaching, while maintaining a high yielding crop.

It would be beneficial for the project to be taken to a larger scale with data captured from more furrows across multiple different fields. This could validate if the level of compaction in tramlines is greatly affected by farming management practices. Furthermore, research could extend into measuring and quantifying the amount of soil compaction in these rows. This could be used to develop a general equation that represents the optimal irrigation duration based on the level of compaction. It could also expand into measuring the yield decline that is caused as a result of the compaction reducing infiltration. By understanding the potential yield and profit loss it can change the farmers mindset on the importance of sustainable management practices. Finally, it was touched base throughout chapter 3 but more research and development into the advance sensors is definitely recommended. Whether it includes making the sensors able to measure across multiple furrow or if it includes redesigning for commercial usage. With software such as SISCO available to simulate and optimise irrigation events, farmers would find large benefits in terms of reduced labour, higher application efficiency and better yielding crops.

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APPENDIX A

Arduino Advance Moisture Sensor Code

Note: Code was created by the Centre of Agricultural Engineering, UniSQ and utilised for the advance moisture sensors.

```
#include <Arduino.h>
#include <avr/io.h>
#include <stdlib.h>
#include <avr/interrupt.h>
#include "config.h"
#include "uSleep.h"
#include "Utils.h"
#include <avr/wdt.h>

/*********CHANGE THESE VALUES DEPENDING ON
REQUIREMENTS*********/
#define contactTime  500  //contact closure time in ms
uint16_t sampleInterval = 120;  //Sample time in seconds
uint8_t thresholdVal = 100; //value change to indicate
water
/********************************************************
*******/

int16_t currentSample = 0;
int16_t previousSample = 0;
int16_t sampleDiff = 0;
int16_t mask = 0;

uint8_t SensorPwrPin = 4;
uint8_t samplePin  = A0;
uint8_t outputPin =  5;

ISR(WDT_vect) {
  wdt_disable();
}

void setup(void) {
  pinMode(SensorPwrPin, OUTPUT);
```

```
  pinMode(samplePin, INPUT);
  pinMode(outputPin,  OUTPUT);
#ifdef DEBUG
  digitalWrite(LED, LOW);
#endif
  digitalWrite(SensorPwrPin, LOW);
  digitalWrite(outputPin, LOW);
#ifdef DEBUG
  Serial.begin(9600);
  //  while (!Serial.available());
#endif
}

void loop(void) {
#ifdef DEBUG
  digitalWrite(LED, LOW);
#endif
  digitalWrite(SensorPwrPin, LOW);
  //  delay(2000);
  timeSequence(sampleInterval); //Delay between
sampling/sleep cycles
#ifdef DEBUG
  digitalWrite(LED, HIGH);
#endif
  digitalWrite(SensorPwrPin, HIGH);
  ADCSRA |= (1 << ADEN); // Turn on ADC
  ADCSRB |= (1 << ACME); // Turn on Analog Multiplexor
  delay(50);  //50ms delay before sampling
  currentSample = (analogRead(samplePin));// * 5000) /
1023;
  sampleDiff = (currentSample - previousSample);
  previousSample = currentSample;
  //  mask = sampleDiff >> 15;
  //  sampleDiff = sampleDiff ^ mask;
  //  sampleDiff = sampleDiff - mask;
#ifdef DEBUG
  Serial.begin(9600);
  delay(5000);
  Serial.print("Current Sample: ");
  Serial.println(currentSample);
  Serial.print("Sample Difference: ");
```

```
  Serial.println(sampleDiff);
  Serial.println("***************************");
  delay(2000);
#endif
  if (sampleDiff > thresholdVal) {
#ifdef DEBUG
    digitalWrite(LED, HIGH);
    delay(1000);
    digitalWrite(LED, LOW);
    delay(1000);
    digitalWrite(LED, HIGH);
    delay(1000);
    digitalWrite(LED, LOW);
    delay(1000);
    Serial.println("True");
    Serial.println("***************************");
#endif
    digitalWrite(outputPin, HIGH);
    delay(contactTime); //Contact close time
    digitalWrite(outputPin, LOW);
  }

}
```

APPENDIX B

MATLAB Code for Converting GPS Coordinates to Distance.

```
%% Dissertation Project
% Haversine formula to calculate the distance between two GPS
coordinates
% Author: Isaac Halling
% Date: 05/10/2022

clc, clear

% Create Function
function distance = haversine(coord1, coord2)

    % Convert degrees to radians
    lat1 = deg2rad(coord1(1));
    lon1 = deg2rad(coord1(2));
    lat2 = deg2rad(coord2(1));
    lon2 = deg2rad(coord2(2));

    % Haversine formula
    dlat = lat2 - lat1;
    dlon = lon2 - lon1;

    a = sin(dlat/2)^2 + cos(lat1) * cos(lat2) * sin(dlon/2)^2;
    c = 2 * atan2(sqrt(a), sqrt(1-a));

    % Radius of Earth in kilometers
    R = 6378;

    % Calculate distance
    distance = R * c *1000; % Meters
end


% Coordinate Input:
coord1 = [-27.35837, 151.365654];       % Point 1 in Decimal
Degrees
coord2 = [-27.354792, 151.366276];      % Point 2 in Decimal
Degrees

%Solve for Distance
distance = haversine(coord1, coord2);       % in Metres

% Show Distance Value
fprintf('Distance: %.2f m\n', distance);
```

APPENDIX C

Struanville Farming Co Soil Tests Results

Nutrien Ag Solutions

TRADING NAME: Struanville Farming Co	**ACCREDITED ADVISER:** James Innes
ACCOUNT NUMBER:	**PHONE:**
FARM NAME: Struanville	**MOBILE:** [redacted]
CONTACT: Jamie Innes	**FAX:**
AREA (ha): not provided	**EMAIL** [redacted]
DATE: 26 Mar 2024	**LABORATORY:** Nutrient Advantage Lab

Paddock Name	**2A**	**2A**	**2A**
Target production (t/ha)	**12.0**	**0.0**	**0.0**
Laboratory sample number	75889051	75823510	75824318
Profile sampled (cm)	0-30	30-60	60-90
Date of sampling	13 Mar 2024	13 Mar 2024	13 Mar 2024
Evaluation table	Maize Grain Irrigated Inland SE QLD and NW NSW	Maize Grain Irrigated Inland SE QLD and NW NSW	Maize Grain Irrigated Inland SE QLD and NW NSW
Description	2A	2A	2A
GPS Format	DecimalDegrees	DecimalDegrees	DecimalDegrees
GPS Datum	GDA94	GDA94	GDA94
GPS Latitude	-27.466398	-27.466398	-27.466398
GPS Longitude	151.397186	151.397186	151.397186

ANALYSIS RESULTS

Paddock Name	**2A**	**2A**	**2A**
Sample Depth (cm)	**0-30**	**30-60**	**60-90**
Soil texture	Medium Clay	Medium Clay	Medium Clay
EC (se) (dS/m) (Cladj)	-	-	-
Chloride (1:5 H2O) mg/kg	40 - Satisfactory	190 - High	330 - High
Nitrate-N (Group) mg/kg	10 - Low	9 - Low	1 - Low
Ammonium nitrogen (KCl) mg/kg	1 - Sufficient	1 - Sufficient	1 - Sufficient

NUTRIENT REQUIREMENTS

Paddock Name	**2A**	**2A**	**2A**
Area represented (ha)	not provided	not provided	not provided
Target production (t/ha)	**12**	**0**	**0**
Growing Season	2024 Winter	2024 Winter	2024 Winter
NITROGEN (kg/ha)	**156.0 (138.0)**		

RECOMMENDATION: 2A

TIMING	PRODUCT	APPLICATION	RATE	QUANTITY
Preplant	Granulated Urea (Incitec Pivot) (kg/ha)	Direct drill	300 kg/ha	0.0t
NUTRIENT RATES IN PRODUCT RECOMMENDATION				
NITROGEN (kg/ha)			138.0	

SOIL HEALTH		**Result**	**Low**	**Marginal**	**Sufficient**	**High**	**Excess**	**Sufficiency Range**
EC (se) (dS/m) (Cladj)	0 - 30							
	30 - 60							
	60 - 90							
Chloride (1:5 H2O) mg/kg	0 - 30	40						0 - 180
	30 - 60	190						0 - 180
	60 - 90	330						0 - 180

NUTRIENT		Result	Low	Marginal	Sufficient	High	Excess	Sufficiency Range
Nitrate-N (Group) mg/kg	0 - 30	10						30 - 40

	30 - 60	9						30 - 40
	60 - 90	1						30 - 40
Ammonium nitrogen (KCl) mg/kg	0 - 30	1						0 - 5
	30 - 60	1						0 - 5
	60 - 90	1						0 - 5

Struanville Farming Co - 26 Mar 2024 - 2A

Grower Details:

Grower Name:	Struanville Farming Co	**Interpretation Date:**	Tuesday, 26 March 2024
Paddock Name:	2A	**Interpreter Name:**	James Innes
Address:	4356	**Interpreter Phone:**	
Phone:			

Evaluation Parameters:

District:	Pittsworth QLD
Description:	2A
Crop:	Maize
Soil Type:	Black vertosol
Growth Stage:	

Sample Details:

Sample Date:	Wednesday, 13 March 2024
Forecast Plant Date:	01-Sep-2024
Forecast Harvest Date:	31-Dec-2024
Test Date:	Tuesday, 26 March 2024

Output Summary - DEMAND:

	YIELD		
	Low	**Expected**	**High**
Target Yield (t/ha):	9.0	10.0	11.0
Target Protein (%):	9	9.0	9
Grain Removal:	130 kg/ha	144 kg/ha	158 kg/ha
Estimated Nitrogen Transfer Efficiency %:	56.0%	56.0%	56.0%
Estimated Crop N Demand (kg/ha):	231 kg/ha	257 kg/ha	283 kg/ha
Estimated N in Crop (kg/ha):			
N Required For Rest of The Crop (kg/ha)	231	257	283

Output Summary - SUPPLY:

Sample Profile Details:

Barcode	Depth From (cm)	Depth To (cm)	Bulk Density (t/m3)	Nitrate N (mg/kg)	Ammonium N (mg/kg)	Depth Weighting	Mineral N (kg/ha)	Organic Carbon (%)
070272437	0.00	30.00	1.20	9.90	1.40	1.00	36	1
070272423	30.00	60.00	1.30	9.00	1.20	1.00	35	
070272438	60.00	90.00	1.40	1.10	1.00	1.00	5	

Soil Mineral N:	75 kg/ha	75 kg/ha	75 kg/ha
Rotation Credits:	0 kg/ha	0 kg/ha	0 kg/ha
Soil Mineralisation Credits:	26 kg/ha	26 kg/ha	26 kg/ha
Manure Credits:	0 kg/ha	0 kg/ha	0 kg/ha
Estimated Total Available N:	101 kg/ha	101 kg/ha	101 kg/ha
Recommended Nitrogen Rate:	**130 kg/ha**	**156 kg/ha**	**182 kg/ha**

Comments:

[Comments for depth 0.00 to 30.00]

[Comments for depth 30.00 to 60.00]

[Comments for depth 60.00 to 90.00]

IMPORTANT NOTE:

You acknowledge and accept that the Services are provided to you in accordance with the Terms and Conditions for the Supply of Farm Services which can be viewed at www.nutrienagsolutions.com.au on the Terms and Conditions page. By continuing to instruct us to perform the Services, you accept the Services on these terms and conditions.

This report is prepared for the purpose of providing general information about the samples obtained at your direction from a specific location. Unless agreed otherwise, samples are taken randomly from the specified location at the discretion of Nutrien and multiple samples from the same location or area are mixed. Nutrien does not itself test samples. Unless you have nominated a particular laboratory, samples are sent to third party laboratories nominated by Nutrien with instructions describing the type of analysis requested. Nutrien will pass on the results of the analysis performed by the third party laboratories (as set out in this report).

Agronomic information or advice provided in this document is based on the results provided by third party laboratories (which we have not verified for accuracy or completeness). These results may vary depending on seasonal and/or prevailing conditions as at the time of sampling as well as the sampling and collection process. The information provided in this report is subject to the inherent variability of soil characteristics and the potential for errors or limitations in the sample collection process as well as the accuracy and representativeness of the collected samples. It is also based on data and observations available to us at the time of preparing the report. We do not represent or warrant that the information in this report is exhaustive, complete or suitable for any particular purposes.

The evaluation and recommendation reports provided here are a guide only, and depend on representative samples being analysed. Additionally environmental and managerial factors influence production, therefore as suppliers of this report, we do not accept any liability whatsoever arising from the application of recommendations, for any damage, loss or injury of any nature and the user takes these evaluations and recommendations on these terms. This recommendation is made in good faith, based on the best technical information available.

APPENDIX D

Risk Assessment

UniSQ

Risk Assessment [Ref Number: 6166] - Live

Date Printed: Wednesday, 13 November 2024

Risk Factors

Risk Factor	Chemicals and Hazardous Substance

Description

(1) Polyurethane resin potting compounds for setting electronic components.
(2) Spray paint
(3) Silicone sealants
(4) Lubricants (WD40, RP7 etc)
(5) Adhesives (sikaflex, liquid nails etc)
(6) Paint
(7) Butane for heat gun

- Does the work involve Chemicals that are NOT classified as hazardous by SafeWork Australia? -- Yes
- Does the work involve:
- Chemicals classified as hazardous by SafeWork Australia? -- Yes
- Does the work involve Nanomaterials? -- No
- Does the work involve or could there be exposure to:
- Does the work involve materials that can cause injury, illness or property damage:
- During product storage and handling, is there a risk of spills or leaks? -- Yes
- Are there regulatory requirements for disposal of the chemical or hazardous substance (chemicals will likely require tracked disposal)? -- No
- Are there any other Chemical or Hazardous Substances hazards associated with the work? (please specify in the above text box) -- No

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Reports identifying people are confidential documents.
Statistical information shall only be used for internal reporting purposes.

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UniSQ

Risk Assessment [Ref Number: 6166] - Live

Date Printed: Wednesday, 13 November 2024

Name	**Isaac Halling Dissertation Project Risk Assessment**	**Current Rating**	**Residual Rating**
		Low	Low
Location	**Off Campus: Various off-campus and on-campus locations: * on-campus: P6 workshop, Ag Plot and Flume, P9 * off-campus: field sites incl. Bowenville (Struanville Farming Co)**		

Business Unit	**Last Review Date**	**Risk Owner**
Office of Research	12/11/2024	Isaac Halling

Risk Assessment Team	**Risk Approver**
Simon Kelderman, Joseph Foley	Malcolm Gillies

Additional Notes

Describe task / use

"Surface Irrigation Variability Analysis and Modelling using Advance Furrow Sensors", Honours Year Research Project

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Low	Low
Existing Controls	**Proposed Controls**
• 6 - PPE: Wear gloves, face protection, P2 mask. • 5 - Administration: Use in well ventilated area. • 5 - Administration: Follow SDS. • 4 - Engineering: Store flammables (butane cans, methylated spirits) in flammables cabinet according to policy.	

Risk Factor	Fieldwork, Domestic and International Travel

Description

Fieldwork at remote farm sites. Marginal mobile phone coverage. Most fieldwork during summer.

- Does the fieldwork activity or travel need to take into consideration:
- Extremes of heat or cold including personal exposure -- Yes
- Fatigue e.g. Jetlag, driver fatigue and hours of work -- Yes
- Manual handling e.g. luggage, equipment -- Yes
- Remote work locations, isolation, working alone -- Yes

Low	Low
Existing Controls	**Proposed Controls**
• 5 - Administration: Undertake remote fieldwork with 'buddy' when possible. • 5 - Administration: Notify farm manager of arrival/departure and location at site. • 6 - PPE: Carry first aid supplies • 5 - Administration: Manage workload according to weather (especially heat). Ensure adequate fluids available. • 1 - Elimination: During hot weather, avoid heavy work in the sun. Work early morning or in evening instead. • 5 - Administration: Long distance driving in accordance with UniSQ policy. Regular rest stops. Do not drive fatigued. • 4 - Engineering: Use satellite personnel trackers / check-in devices -available at UniSQ Safety Office • 5 - Administration: Regular check-in with responsible person. Have protocol for missed check-ins	

Risk Factor	Weather

Description	
Hot weather during fieldwork. Heavy rain with flooding	• Is there the potential for:

Low	Low
Existing Controls	**Proposed Controls**
• 1 - Elimination: Re-schedule fieldwork to avoid very hot weather • 5 - Administration: Undertake fieldwork in early morning or in the evening to avoid peak solar loading. • 1 - Elimination: Re-schedule fieldwork to avoid flooding on roads. • 6 - PPE: Adequate supply of fluids. • 5 - Administration: Fieldwork with buddy where possible	

UniSQ
Risk Assessment [Ref Number: 6166] - Live
Date Printed: Wednesday, 13 November 2024

Risk Factor	Other

Description	
Use of hand tools and power tools in the P6 workshop, Ag Plot, and at fieldsites.	• -- --

Low	Low
Existing Controls	**Proposed Controls**
• 5 - Administration: Use tools according to SOP's. • 6 - PPE: Use appropriate PPE with the tools.	

Risk Factor	Animals

Description	
Bites from snakes, spiders at field sites.	• Does the work involve:: • Is there potential for:

Low	Low
Existing Controls	**Proposed Controls**
• 6 - PPE: Wear above-ankle boots or gumboots, long trousers, and/or chaps. • No existing controls required: Proceed cautiously in high-risk areas e.g. native vegetation, fallen logs • 6 - PPE: Carry appropriate bandages on person and/or in first aid kit	

Appendix

Documents Referenced
CAE Project - 1008258 Risk Assessment

Risk Matrix Level	
Very Low	Task can proceed upon approval of the risk assessment by the relevant supervisor, manager or higher delegate
Low	Task can proceed upon approval of the risk assessment by the relevant supervisor, manager or higher delegate
Medium	Task can proceed upon approval of the risk assessment by a Category 4 or higher delegate
High	Task can only proceed in extraordinary circumstances provided there is authorisation by the Vice Chancellor
Extreme	Task must not proceed. Appropriate and prompt action must be taken to reduce the risk to as low as reasonable practicable