University of Southern Queensland
Faculty of Health, Engineering and Sciences

Retrofitting and Redesign of Irrigation Systems

A thesis submitted by:

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Abstract

Water is the most important part of any crop or stock production business and irrigation is used to apply that water to a desired area of a farming operation. Some of the more popular methods for applying that water is through the use of lateral moves or centre pivot systems. But as time passes, the land change hands or the infrastructure in place ages and due to changing outlooks or age the system doesn't fit the owner's requirements anymore. This then leads to the system being used less or used in its current state which means that the system is not being used or isn't operating at peak efficiency, and in a world that is having to produce more food off the same amount of land efficiency is key.

The reason that this research topic was chosen is that due to the large amount of capital required to install a irrigation system and existing infrastructure can be upgraded to extend the working life of the machinery for a smaller amount of capital to improve the efficiency of the machinery and in turn increase the use of these machines. Therefore, the main outcome of this research is to design a template that can be done in part by the owner of the machine and consulting with their sales representative to come up with a solution to extend the life of the machine. This will then flow onto coming up with a chekclist to be proformed by the owner before the evaluation of the system and then a triffic light approuch to updating the machine and fasablity if the machine is worth updating and a new machine could be installed in its place.

By the development of the initial version of the checklist and discussing the feasibility of retrofitting of the machines I hope that the irrigation sector of agriculture will have a more standardized approach to the upgrading of its infrastructure.

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ENG4111/2 Research Project

Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged. I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Signed: Darcy Diderick Mossman

Acknowledgments:

Over the course for writing this dissertation there have been some people that I would like to thank, first off is my parents Keith and Julie Mossman for one letting me use and run their centre pivots for my data collection and secondly for always being at my back over this year to help me through this year,

Secondly, I would like to thank Nathan Prain who started me on this part on doing my thesis on irrigation systems.

The finally I would like to thank Doctor Macolm Gilles who helped my out a lot in the early parts of this project with defined scope and pointed me in the right direction over this year.

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Chapter 1: Introduction and Objectives

1.1 Introduction

The main basis of this project is to discuss the retrofitting and upgrading of irrigations systems, and part of this will be to talk about the design process of new infrastructure and how existing or outdated infrastructure can be reused. Water the most important resource in the agriculture sector as it is the source that governs how productive a parcel of land can be, either by water for crop production or water for livestock and one of the ways that water can be put to use is through irrigation. Irrigation comes in many forms and basin management irrigation has been in use since Ancient Egypt, (University of Wisconsin, 2023), and has been has a major contributor for food and fodder production ever since, and one of the most popular methods of irrigation in Australia is by the use of centre pivots or lateral move sprinkler systems as these allow the owner to accurately put on water over large areas. But when outlooks or land changes hands the infrastructure stays and often have different purpose than what it was designed for, these can be a different crop, water allocations or that their circumstances are now different from when they were installed. Ill-suited machines then lead to assets being underutilized due to under or overwatering in their new job description. This is where the following will would like to focus in on but before then a breakdown of what a centre pivot is will be done next.

One of the main reasons that the student has decided to take on this project is due to their access to 6 centre pivots of varying size, age as well as the amount of water available to them, on the land owned by K.D. and J.J. Mossman, 20 minutes north of Mundubbera which is 4 hours northwest of Toowoomba. The picture below is of 'Fairvale', which has one of the machines that will be used for the data collection phase of the project. This as well as the possibility of using the 2 lateral machines at the University of Southern Queensland's Toowoomba campus if there is a need for more machines. The use of up to five machines that will form a pool of machines to be selected from to collect data from and more data to be collected if there is time permitting, both the collection and discussion of additional data.

Figure 1.2 Satellite view of Fairvale, Source (Google Maps , 2022)

1.2 Objectives and Aims

The aim of this paper is to evaluate existing irrigation systems on their performance and the suitability for their given task. By investigating how new machines compare to older ones and noting the shortcomings of older systems a guide can be made on how best to approach the retrofitting of the older system.

The components that make up an irrigation system are what will be explored in the first part of the literature review as understanding how each of the components contributes to the systems as a whole will aid in understanding what areas an installer could look at updating to improve the efficiency of the existing infrastructure. Data will be collected to provide us with a way to directly compare the systems and review what works and what can be done better to improve the aging machine. The data points that will be collected will be detailed in chapter 3.

Chapter 2: Literature Review

2.1 The Birth of the Centre Pivot

Before the invention of center pivots and lateral move the only thing that was on the market for a movable sprinkler system was hand pipes where at the end of each irrigation cycle the must be moved by hand to the next part of the field that was to be watered but, in 1947 a farmer by the name of Frank Zybach from Columbus Nebraska, went to an irrigation field day in Prospect City Colorado and saw the hand pipes on display and decided that there was a better way to irrigate.

Figure 2.1: One of Zybach first center pivots, Source (Living History Farm, 2021)

Then over the next year Zybach designed a small-scale water driven machine, that uses a water piston to drive the wheels and by June 1949 he had a patent for his design, a picture of one of the first Zybach machines is pictured above, summarized from (University of Nebraska-Lincoln , 2023). These first simple irrigators used water as their power source as well as applying it to the field that they are on but the pipe that the water was pumped into was low to the ground and by 1953 Zybach had raise the pipe to 9 feet or 2.7 meters above the ground to rectify this. By 1954, Zybach had sold the manufacturing rights to Robert Daugherty of the Valley Manufacturing Company and was paid a percentage of each sale for the remainder of the patient's life span (National Inventors Hall of Fame , 2023).

2.2 What are Centre Pivots and Lateral Move Systems

Centre pivots and lateral move irrigation systems a type of sprinkler irrigation that is self-propelled to either run in circles or part circles for centre pivots or straight lines in the case of lateral moves. Both systems allow the producer to irrigate large parcels of land accurately over the area. With the sprinkler packages on laterals being constant throughout they are much easier to set up for a given application rate. Whereas centre pivots the amount of water applied gets progressively larger the further away from the centre the sprinkler is positioned and because of this sprinkler packages for these machines are a bit harder to put together due to the nature of the system.

Figure 2.2: Picture of Fairvale Pivot Running, Source Student

2.3 Updates and Improvements

Over the year many updates have been made to the base design one of the biggest advancements was to use electric motors to drive the machine instead of the water driven pistons that where being used in the earlier designs, also what came along with electric motors was the use of nematic rubber tires were starting to be used on centre pivots. Then in 1982 computers were starting to be used to aid with irrigation scheduling, this meant the machine could move at a set rate to apply different amounts of water due to the electric motors and the on-board computer. Then the most recent addition to the design was the introduction of GPS to be installed on to the machine, this means that the machine can be programmed to only water part of a field without the use of stoppers. This also is known as the stop in slot, or SIS, the GPS tracks the position of the machine and with the control panels on newer machines having full colour displays that show the machines relative position the stop in slot feature is a vital part of the system. Because of this development GPS is now a standard piece of equipment on all machines, (Valley Irrigation, 2023).

2.4 Irrigation Uses in Australia

Irrigation in Australia is used in a large number of industries, in the agriculture sector, including cropping, small crops, tree crops as well as uses for fodder production. Figure 2.3 depicts the major crops that utilise irrigation in the business to grow there produce. The industries that make the best use of centre pivots or lateral moves sprinkler systems are cereal crops, cereal and grass crops used in fodder production and this can be either fed off as processed to be turned into hay or silage. The above-mentioned industries are able to take advantage of centre pivots or lateral move machine the most because of the way the way the product can be farmed as these crops have minimal obstacles in the areas where the machines will operate. And as depicted below in figure 2.3 and figure 2.4 these industries have been having an increased uptake in irrigation over the last 2 financial years, both in amount of water applied and area under irrigation, as centre pivots and lateral moves are the most effective way to irrigate large areas of land and the way these farming operations are set out lend themselves to a centre pivot or a lateral move machine.

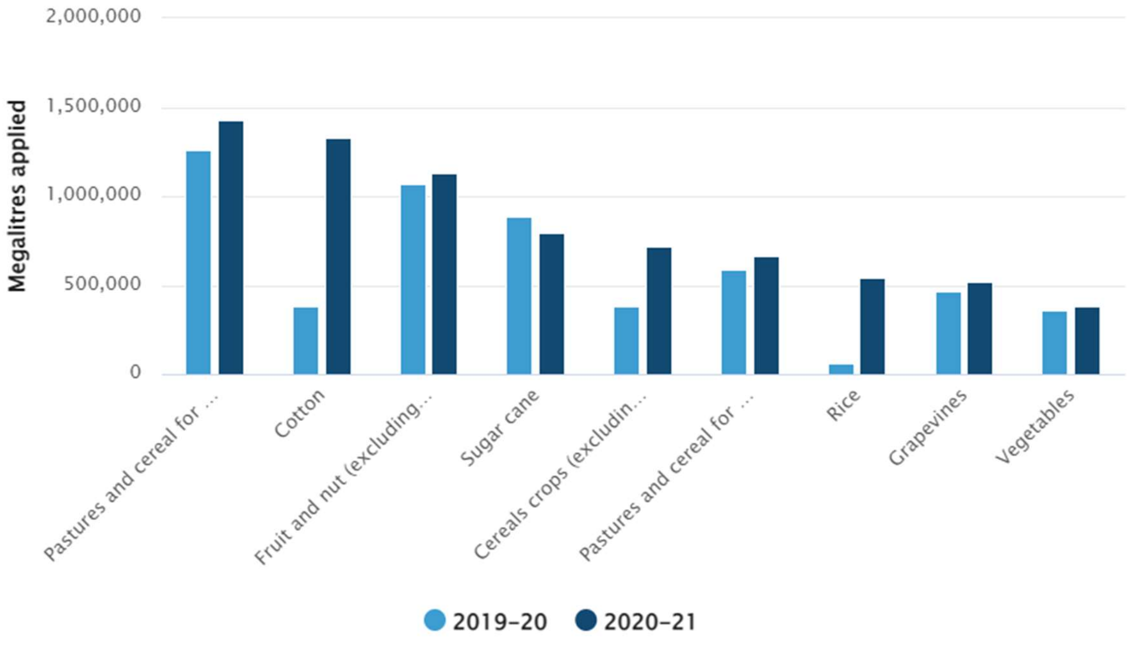


Figure 2.3: Megalitres of Water applied in Australia, Source (Australian Bureau of Statistics , 2022)

Some other ways of irrigating these types of crops are as follows permanent sprinklers, also called solid sets and hand pipes, both of these forms of sprinkler irrigation shine for small areas or areas that access, or where the terrain may not be in favour for a large piece of infrastructure. The main reason why these methods of irrigation are not suited for large scale irrigation projects as the require a lot of time to manage and maintain and due to these short comings they are not suited to large-scale producers as they don't have the time use and maintain these types of systems effectively.

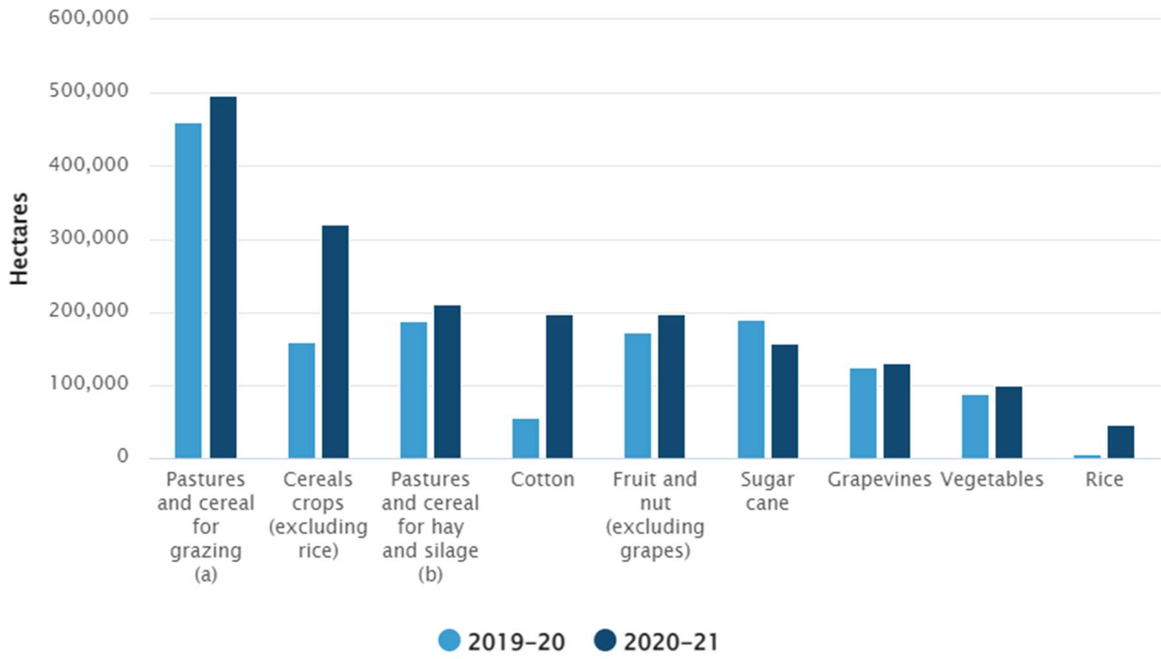


Figure 2.4: Area under irrigation Source (Australian Bureau of Statistics , 2022)

2.5 Mechanical Components

The main mechanical components of a machine are, the spans, the drivetrain and the towers. To start with the spans of the machine are both the method of water delivery and the main structural member of the machine, as the spans are made up of pipe in the shape of a n arc that has a pipeline that is used to deliver the water throughout the machine. The spans are connected at either end of a section to either the centre, or the cart in the case of lateral move machines, or they are connected to a tower, which is an A-frame in which the other components the drivetrain and the wiring are located. The motors on modern machines are then connected to the drive shafts by a spider connection and the drive shafts go to a worm drive gear box on either side of the A frame. The size of the pipe depending on the size of the machine are in the range from 5 inches through to 10 inches, the pipe sizes are in imperial because many manufacturers of the components are based in the United States of America (USA).

2.6 Sprinklers

The sprinklers then come off the main pipe and in most cases are hung from the machine using droppers, length of flexible hose to lower the sprinklers height off the ground, these droppers can then be also hung over the torsion rods to increase the water footprint, the area in which the sprinklers cover to reduce runoff. On the topic of run off it is more of a problem in centre pivots is that there is 75 percent of the water applied in put on the outer half of the circle, so it is advised that the application rate in this outer half doesn't exceed the infiltration rate of the soil. 'The sprinklers are one of the most important parts of the machine as 70 percent of the machines performance comes from having the right sprinkler package fitted to the machine and only costing around 7 percent of the investment of the project', (Cooperative Research Center for Irrigation Futures , 2007). One of the other control methods for runoff when farming under centre pivots to 'tilling the fields in circles in steed of tilling in straight lines across the field as the furrows left by tillage implements will have equal access to the water and will avoid water being dumped in certain furrows which in excessive case can lead to erosion in the field', (Fipps, 2023). Most centre pivots and lateral move machines are fitted with one of the following sprinkler manufacturers Nelson or Senninger. An example of a rotating plate sprinkler from Nelson is depicted in figure 2.5.

Figure 2.5: Example of a Nelson Pivot Sprinkler, Source (Nelson, 2023)

2.6.1 Sprinkler Types

The two most popular sprinkler manufacturers in Australia are Nelson as mentioned above in 2.6 and Senninger and both of these manufacturers offer a large array of different sprinkler options. The first one that will be discussed is the rotating plate type, both of the mentioned companies produce this type with the Nelson pictured above in figure 2.5 and the Senninger one picture in figure 2.6, there are a few differences between the two and the first major on is that of the plate its self, on the Nelson verity the plate only rotates in the horizontal axis and the plate itself changes with the application rate, where the outlets on the plate change as shown with a plate close to the centre of the machine having much smaller outlets. Then on the Senninger type they are of a wobbler design meaning that when there is water going through the nozzle of the sprinkler and this will mean that the plate of the sprinkler moves in both the horizontal and vertical axis meaning that the throw of the sprinkler is different. The second difference between the two is how the jets in the

Figure 2.6: Senninger Sprinkler, Source Student

sprinkler are installed, with the Nelson's having a jet fitted, figure 2.7, before the sprinkler screws in and the jet for the Senninger's being sits down in the sprinkler itself.

One of the few gaps in the water application rate of this type of machine is the parts that are not watered around the wheels and there is one way that this can be fixed is with a section of pipe that is called a boom back. There are two types of boom backs and the first is depicted blow on the right, figure 2.8 and the second the left figure 2.9 Both of these boom backs have part circle sprinklers fitted and the only differences between them are cost and reliability as the one depictured inf figure 2.8 is more stable and covers more area, while the one depictured in 2.9, are easier to fit and adjust the height on.

Figure 2.7: Nelson Sprinkler Jet, Source Student

Figure 2.8: Fairvale Boom Back, Source Student

Above: Figure 2.9: Stockhome Boom Back, Source Student

Below: Figure 2.10: GPS Dome, Source Student

2.7 GPS and Computer Control Systems

Most machines that have been built since the 1982 have a computer operating system and this is put at the centre for centre pivots and with the cart for lateral move machines and this is where the application rate and run time of the machine can be set, (Valley Irrigation, 2023), but in centre pivots equipped with a GPS, shown figure 2.10, unit this is where the stop in slot feature can be used to only water part of the circle if desired, but both types of machine can shut off automatically, if the feature is installed, when they have completed their runtime are equipped with an electronic valve that will shut off the water to the machine so that water isn't being wasted while the machine is stopped. If these valves are to be used any pumps that are used to supply the machine should have pressure switches installed to prevent damage to them as if the value shuts and the pumps either don't have radios or pressure switches fitted, they will dead head themselves. To the right in figure 2.11 is a Nelson value and on the value, there is three positions that of open, closed and auto so the value can still be used in the traditional way to be turned off and on or in auto mode where the value will shut when the machine has completed its irrigation event.

Figure 2.11: Nelson Valve, Source Student

2.8 Pipe

The final component that will be discussed before moving onward is the pipe on both the machine and leading up to the machine which is the case for most centre pivot machines whereas most lateral move machines will either drag a flexible hose with the cart or have a channel alongside the cart where it will draw water from. As stated, before that machines can have different sized pipe fitted depending on the amount of water required to flow through the pipe, opting for small sized pipe will increase the head loss of the system and increase running costs. 'By going with a larger size pipe, the extra investment required will be often paid for in the first or second season, so this is an investment that it often worth the investment', (Cooperative Research Center for Irrigation Futures , 2007).

The Darcy-Weisbach formula is one way that head loss can be calculated. This formula, Shown in Figure 2.12, can be used when the data is collected to calculate the head loss from the friction losses in the pipe. One of the drawbacks to using this formula is that it doesn't factor in head losses from elevation or any elbows or Tee's in the pipework. The main use of this formula in this project is to calculate the head losses due to the friction losses in the pipe. This formula was taken from (Pipe Flow , 2023)

Figure 2.12: Head Loss for of the Darcy-Weisbach Equation, Source (Pipe Flow , 2023)

$$hf = f\left(\frac{L}{D}\right) * \left(\frac{v^2}{2g}\right)$$

Where:

Hf is head loss in meters.

F is the friction factor.

L is length of pipe in meters.

D is the inside diameter in meters.

V is velocity of the fluid in m/s

G is the acceleration due to gravity or 9.81 m/s^2

Chapter 3 Installations and Design Considerations

3.1 Installation

There are three main parts when installing a machine, one is the pump and pipe work to the machine, two is the assembly of the machine itself and then third is the electrical wiring to the control box. The first thing that is done, is laying the pipe work to the machine from the pump and if the machine is a centre pivot the cement slab will be poured at the centre of the circle. Then the machine is built from tower to tower from cart or centre first laying them assembled arch on the ground and then the arch is stood up and connected to the tower that is standing. This is also where the sprinklers are fitted and when the arch is standing the boom backs are fitted, then once the machine is standing the wiring is done last connected to the control box and the GSP is brought online and synced up to the machine.

3.2 Design considerations

When designing a system from the ground up on of the first things is what is going to be put under the machine and how much water is at your disposal, this is both the amount of water that can be pumped in litres per second or other similar unit as well as how much water is available to be pumped, an example could be how much water is on the customers water license to be pumped either from a river or underground aquifer, this determines the size of the machine that can be installed, (Pain, 2023). Centre pivots and lateral moves have sprinkler packages that that with the length and amount of water available for the machine rated on how much water can be put on in a 24hr period.

3.3 Reasons for Changes

Changes or updates to existing infrastructure happens for a few reasons and some examples are changes to water allocations, changes to the crop grown under the machine, upgrades to the surrounding infrastructure, convenience or to improve the efficiency of the system as a whole, each or these have their own merits and will be briefly explained below. Changes to water allocations in cases where to water is increased the will in turn this will increase the amount of time per season the client can water for this in turn will increase the production of the land, this can also happen in the inverse where there are water restrictions put in place therefore restricting the amount of water that can be used. Surrounding infrastructure is the pumps and pipe that lead up the machine upgrades to one or both of these will affect the system. Upgrading the pump will increase the flow and volume of water where increasing the pipe size will reduce the amount of head loss to the system and therefore reducing the running costs of pumping the water. The pipe size and sprinkler packages are the two main factors that affect the efficiency of the system. Then convenience is down to the client wear changing the control boxes to match maybe the upgrade that will make the most sense as having multiple machines with the same control panel will would be a good thing from a training and familiarity stance.

Chapter 4: Planning and Data Points

4.1 Data Points

The first set will be to take notes on the system that is already installed, these parameters will be:

- Length of the machine
- Length of pipe work
- Pipe size
- Application rate of the machine per 24 hours
- Pressure at the water inlet of the machine as well as the end pressure.
- Flow rate
- Line pressure at the pump

Using these collected data points and consulting the owner of the machine on what they plan to use the machine for a process can be started to how the system can be evaluated.

These data points have been selected because, for the Pipe size and length this is required to calculate the head loss or friction loss in the pipe work, the line pressure and the pressure at the centre or end of the machine are for the real pressure losses in the system and that the pressure at the centre of the machine aid in the sprinkler package design so that there is enough pressure in the entire machine for the sprinklers to operate properly, the flow rate is to help with this as well as the head loss calculations and finally the application rate is to identify the amount of water applied by the system.

Some questions that will be asked of the owner are detailed below.

- What will this machine be used to grow? A summer Crop, winter crop or fodder production?
- How much water is required for the crop to grow?
- How often is this machine going to be used?

4.2 Data Collection Plan

For the collection of data from the centre pivots the first step of the process is to start the system and let the pumps equalize to their operating pressure, then take note of the line pressure and then head out to the centre of the machine and note the pressure at the centre. The other data points can be collected while the machine is off and these include the pipe size and length, the length of the machine, application rate and the flow rate the pump is rated to. The pressure at the end of the pivot was not collected due to the machines not being fitted with them and that data point was not recorded and may be collected later if there is time left to install the pressure gauges.

4.3 Resources Required

Resource	Number Required	Supplier	Cost
Machines for data collection	3	K.D. and J.J. Mossman and UniSQ possibly	Nill
Computer for data collection and Report write up	1	D.D. Mossman	Already Acquired
Side-by-side for data collection	1	K.D. and J.J. Mossman	Nill
Hand tools for installing gauges for data collection	1	D.D. Mossman	Already Acquired
Microsoft Office	1	UniSQ	Nill

Figure 4.1: Table of Required Resources

Chapter 5: Project Development

5.1 Methodology

The project will be broken down into 6 main phases and they are detailed below.

Phase 1 Conduct initial research on irrigation setups as well as a breakdown of the components and uses of irrigation.

Phase 2 Review how irrigation systems are designed and installed.

Phase 3 Initial write up of report, this will be at the completion of ENG 4111 Research Project Part 1.

Phase 4 Take measurements of at least 2 machines, the data that is to be collected has been detailed above.

Phase 5 Analysis of the collected data comparing the points of the old and newly built machines.

Phase 6 Develop a process to evaluating the systems as well as proposed changes required to the system.

5.2 Limitations

Time is the main limitation of this project as the time allocated for the completion of this project is the 15th of October 2023, with this given due date this will limit the number of machines used in the data collection and analysis phase of this project. This is also compounded by the fact that the student has other commitments during the allocated time period. The second main limitation is the travel time required for the student to go and collect data, which is both a time and financial limitation. The final limitation is getting access to the properties that the irrigation systems are on. This will limit the number of machines the student can collect data from, also on the topic of time the Christiansen uniformity coefficient ,which is discussed below in chapter 7, is a method that is used to calculate the distribution efficiency of an irrigation event and involves laying out catch cans under the sprinklers and as this take time to set up and run, due to the pivots being used are in an active fodder and grazing operation there was not an opportunity for this data collection event to be run on these machines.

5.3 Expected Outcomes

- Initial Plan for checking the machine.
- A traffic light approach to upgrading and retrofitting.
- Test the checklist and traffic light approach on one of the machines where data was collected from.
- Discuss results from above.

Chapter 6: Data Collection and Analysis

6.1 Data Collected

	Stockhome Valley	Fairvale Valley	Stockhome Pierce
Pipe Length	474 m	1100 m	395 m
Pipe Size	6 in.	8 in.	6 in.
Length of Machine	324 m	328. 7m	230 m
Application Rate	5mm/24 hr	10.14 mm/24hr	15 mm/24hr
Flow Rate	40 l/s	50 l/s	40 l/s
Line Pressure, at Pump	40 psi	70 psi	40 psi
Pressure at Centre	23 psi	33 psi	18 psi
Pressure at End	14 psi	25 psi	15 psi

6.2 Data Collection Process

The process for collecting the data from the three machines was to first start the pumps and centre pivots and let the run for 5 minuets for the pipeline to fill and get the pumps into there operating speeds. Then once the pumps have filled the line and got up to pressure the line pressure at pump is recorded. For the flow rate on the system at Fairvale there is a variable speed drive, VSD, fitted to the machine with a live read out with a flow meter installed, the average flow rate displayed was recorded at 50 L/s. For the older system at Stockhome there is no VSD fitted on this system only a soft starter so once the pump is running the pump will only operate at its rated flow rate. Due to the age of the system the plate is longer with the pump, but because the pipeline is fitted with a water meter, figure 6.1, the pump was timed on how long it would take to pumps one meter cubed of water and then the flow rate was calculated from this data. To convert the meters cubed to litres per second, it is known that one meter cubed is 1000 litres and then we take the time required to pump a meter cubed then dived it by time taken. The average time taken was 25 seconds therefore the flow rate for this system is 40 L/s. Then the pressure at the centre is recorded, this can be obtained through a gauge on the standpipe of the machine, figure 6.2, or on the digital readout of newer machines, then the end pressure is found by reading the gauge at the end of the machine.

Figure 6.1: Water Meter, Source Student

The next set of data is obtained by manual of the machine which the producer would have received at the completion of the machine, and this includes the length of the machine, and the application rate of the machine will also be here. For the length of the pipeline to the machines a trundle wheel was used to walk along the path of the pipe to find of the length of the pipeline. Then with knowledge of the pipeline that runs towards the machines the pipe size is given in imperial inches but for use in the Darcy-Weisbach equation these will need to be converted to metric sizes this means that the metric sizes for these pipes to be 150mm and 200mm respectfully.

Figure 6.2: Pressure Gauge on Standpipe, Source Student

Some interesting notes about the pressure drop from machine to machine is that even though the Valley Stockhome machine doesn't have an end gun or R55 rotating sprinkler fitted there is still 9 Psi loss from the centre to the end and this is due to there being a large number of weeps and leaks in the system. This can be the reason why there is more pressure drop in this machine compared to the Fairvale machine, which has less pressure drop even though this machine has a R55 sprinkler fitted to the end of the machine. Also, it should also be noted that two machines that are at Stockhome run off the same pump systems and only have a different pipeline to run to the separate machines.

6.3 Data Analysis

The main part of this section will be on the friction losses in pipe, as stated in the section above the pipe sizes were recorded so that they could be used for the Darcy-Weisbach formular for head loss and the other data point that is required from the collected data is the flow rate. For the calculations that follow since pressure loss is what is being calculated the pressure loss version of the Darcy-Weisbach formular will be used which is detailed in figure 6.3 and the two values that need to be calculated are friction factor and the velocity of the fluid. For the velocity of water is depicted by figure 6.4 and where Q is the flow rate in meters cubed per second and A is the cross-sectional area in meter squared. The flow rate from the data collected is in litres per second to convert this to meters cubed per seconds the value in litres per second is divided by 1000 to give an outcome in meters cubed per second.

$$\Delta p = L \cdot f_D \cdot \frac{\rho}{2} \cdot \frac{v^2}{D}$$

Above, Figure 6.3: Darcy Weisbach Equation for Pressure loss, Source (Engineer Excel, 2023)

Below Figure 6.4: Calculation for Water Velocity, Source (Engineer Excel, 2023)

$$v = \frac{Q}{A}$$

Calculating the friction, the coefficient is a more involved process as first using the equation in figure 6.5 to calculate the Reynolds Number where p is the density of water, v is the velocity of water, D is the diameter and u is the viscosity of water. For the Darcy-Weisbach equation to work the friction factor

$$\mathrm{Re} = \frac{\rho v D}{\mu}$$

$$f = \frac{64}{\mathrm{Re}}$$

Top, Figure 6.5: Reynolds Number Equation, S

Bottom, Figure 6.6: Laminar Friction Factor, Source, Both, (Engineer Excel, 2023) and the relative roughness ness to be calculated. The first of these that will be discussed is the friction factor as there are two ways to calculate it depending on if the water in the pipe is turbulent or laminar, if the water has laminar flow the equation in figure 6.6 is used where the friction factor is 64 over the Reynolds number. If the Reynolds number is over 4000 the water is completely turbulent and the Colebrooke equation is to be used to find the friction factor and is shown in figure 6.7 where ε is the roughness of the pipe material, D is the diameter of the pipe and Re is the Reynolds number and this is solved for f, which will give the friction factor in the case where Re is greater than 4000. Then as seen in figure … the Reynolds number has been calculated, then using the moody diagram, figure …, and either the relative roughness or the friction factor it can be found that the water in both of these cases is completely turbulent.

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\epsilon}{3.7\,D_h} + \frac{2.51}{Re\,\sqrt{f}}\right)$$

Figure 6.7: Colebrook Equation for Friction Factor, Source (Engineer Excel, 2023)

6.4 Results

When calculating the pressure loss for the pipe there where two cases that were calculated one on the collected data and one case on laminar flow to identify the ideal case of pipe flow. First for the ideal case using laminar flow there is only one change here and that will be not using the calculated Reynolds number as this is what determines if the flow is laminar, critical or turbulent and will instead use the Reynolds number of 2000 as this is the highest the Reynolds number can be without becoming turbulent this is to show the losses in the ideal state where the whole pipe is filled with water and there is no air in the water. Therefore, the equation that was using for finding the friction factor is depicted in figure 6.6 which is used in the case of laminar flow. In figure 6.8 the two pipelines for the laminar case are graphed and the results of the Fairvale pipeline have a 32.23 Psi drop over 1100 meters and the Stockhome line has a Psi drop of 37.46 over the 474 meter distance. This was to create a base line for the ideal case for each of the systems assuming no change in elevation and that the pipe is in a straight line to the machine.

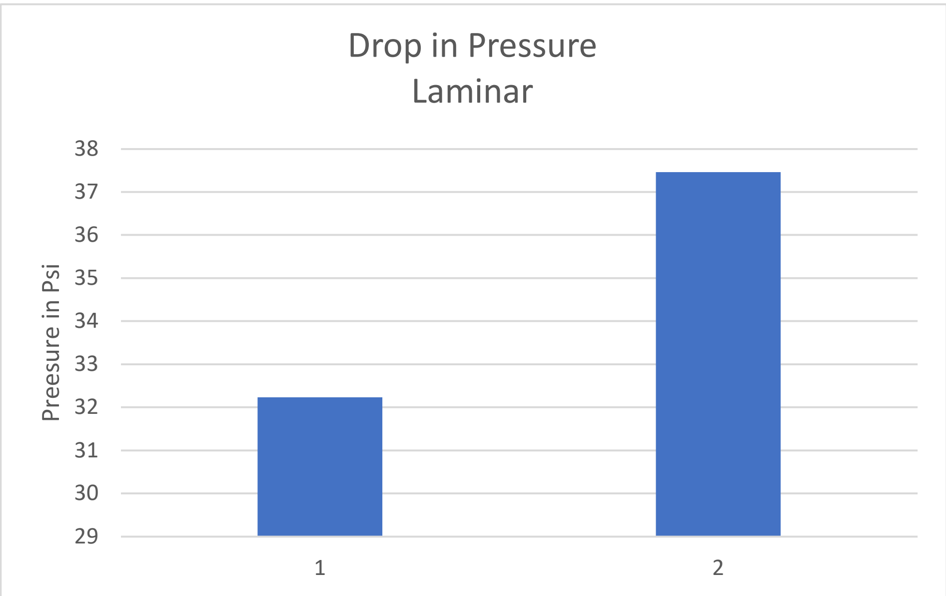


Figure 6.8: Graph of Drop in Pressure for the Two Cases, Source Student

The second was using the obtained data but is still assuming that the pipe is in a straight line to simplify the process of calculating the data as this data is to show that the pipe size will matter when it comes to friction loss when building or updating a machine as each system that will be looked at has its own unique set of variables, being change in elevation or the number of T joints or elbows to direct the flow of water to the machine.

Since the Reynolds number for the obtained data well exceeds 2000 and was calculated as 325 927 for the Fairvale line and 347 656 for the Stockhome line the Colebrooke equation was used to calculate the friction factor for this section of data. The actual flow case pressure drops are depicted in figure 6.9 and shows a 14.43 Psi drop for the Fairvale line and a 16.60 Psi drop for the Stockhome line. The pressure drops where converted from there output in pascals to Psi to keep the same units of measure that was used in the data collection so that it is easier to compare between the calculated and obtained values. Even though the Fairvale line is 2.32 times longer than the Stockhome line the pressure drops are comparable to each other and if we were to set a test length of pie of 500 meters and using all the same data the pressure difference would be much higher. This shows that the size of the pipe is quite important when installing or upgrading a pipeline as the increase in friction from the smaller pipe will impact on the power draw of the pump, which leads to higher pumping cost when using the irrigation system and as stated above in chapter 2.8 the costs of installing larger pipe can be recouped within the first few seasons depending of use in the costs of pumping.

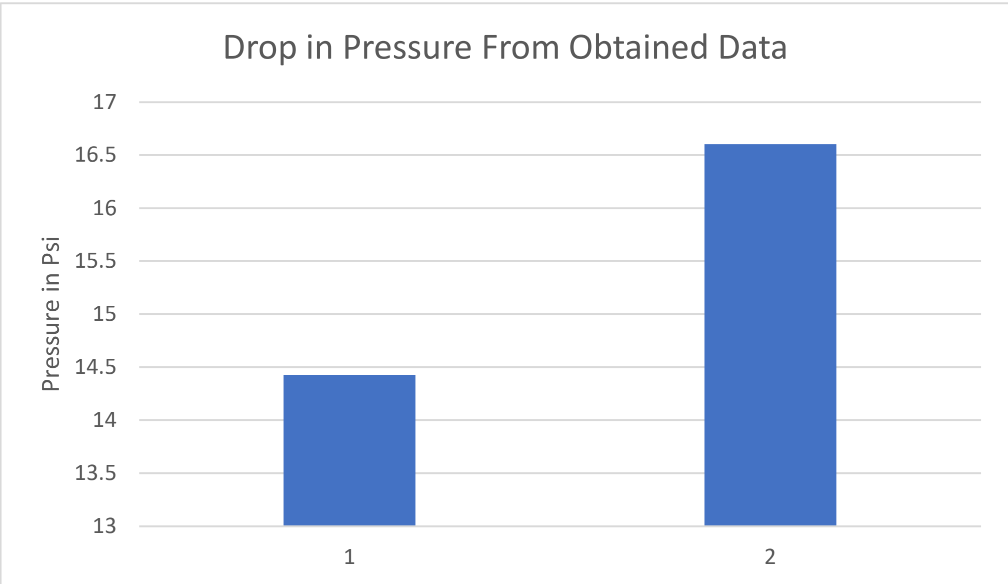


Figure 6.9: Graph of Drop in Pressure
for the Two Cases, Source Student

Chapter 7: Initial Evaluation Plan

7.1 The List of Checks and Discussion

Visual Checks

- Check Pipeline and Main Pipe on Machine for leaks.
- Check that the sprinklers are in the proper position.
- Inspect motors, drive components and tire condition.
- Record pressure at the pump head, input of machine and end of the machine.
- Inspect that all sprinklers are operating as intended, if they are a rotating plate make sure that they are rotating, exacta.

Hydraulic Checks

- Flow rate of the pump
- Operating pressure of the machine, eg. The regulators on the sprinklers may require a stated pressure to open fully and operate as intended.
- Rated Application rate.

These checks are to ensure that the machine is operating as intended and that it is in its best possible condition before assessing the machine. The visual checks are something that can be done by the owner either on their own or recommended by their sales representative before they come on site. This will aid with narrowing down if there are any preexisting issues with the machine or issues that will need to be rectified to make the machine work effectively, these are issues like drive motor condition, tire condition because if the machine walks too far out of line the safety override will activate to save the machine from breaking due to an alignment issue. The pressures are taken as these are one of the best ways to see if the machine is performing at its best, because if there is a large drop in pressure either from the pump to the machine or the water entry of the machine to the end this is what needs to be fixed before anything else can be determined. This helps with narrowing down the problem from the line from the pump or the line in the machine itself.

Once it has been found that the machine has no visual or mechanical problems some of the more deeper rooted issues of the machine can be brought to light, these issues can be less prevalent when other issues are present so the first set of visual checks is to eliminate more common and major issues before getting to the next step which are focused on the delivery of the water. Some machines are fitted with regulators to regulate the pressure sprinkler to even out the pressure differences but on some machines that have low pressure these cannot let the full amount of water get to the machine due to there not being enough pressure to make the regulators stay in their open position. The rated application rate for the machine as stated before is the amount of water applied in 24 hours and is recorded to see one to find the application rate of the machine if it is unknown and also to see if there are any inconstancies with the water application. With most centre pivot and lateral move machine if there is no excessive pressure drop between the water entry and the other end of the machine the uniformity of the water applied will be quite high but if there is excessive pressure drop the sprinklers of the far end of the machine will not be as effective, especially in the case of centre pivots as the further along the machine the larger the jet on the sprinklers are and thus are more effected by the drop in pressure.

On the topic of uniformity one of the most common ways that it is calculated is by using the Christiansen uniformity coefficient which calculates the efficiency of sprinkler-based irrigation. In this method catch cans are laid out over the area the sprinklers cover and after the irrigation event is finished depths of the catch cans is measured and is calculated by the equation shown in figure 7.1 where x bar is the average of the applied depths and m is the is the average deviation from the average depth applied. By using this equation the uniformity of an irrigation event will output as a percentage and the more catch can that are used the more accurate this percentage will be. This is used to make sure that the system is putting the stated amount of water on and a higher percentage means that the irrigation event is suppling the stated amount of water along the length of the machine meaning that the water applied is consistent throughout the machines length.

Christiansen Uniformity Coefficient (CU)

$$CU = 100\left(1 - \frac{m}{\bar{x}}\right)$$

Figure 7.1: Christiansen Uniformity Coefficient, Source ENV 4106 Study Book

7.2 Pyramid Pricing Evaluation

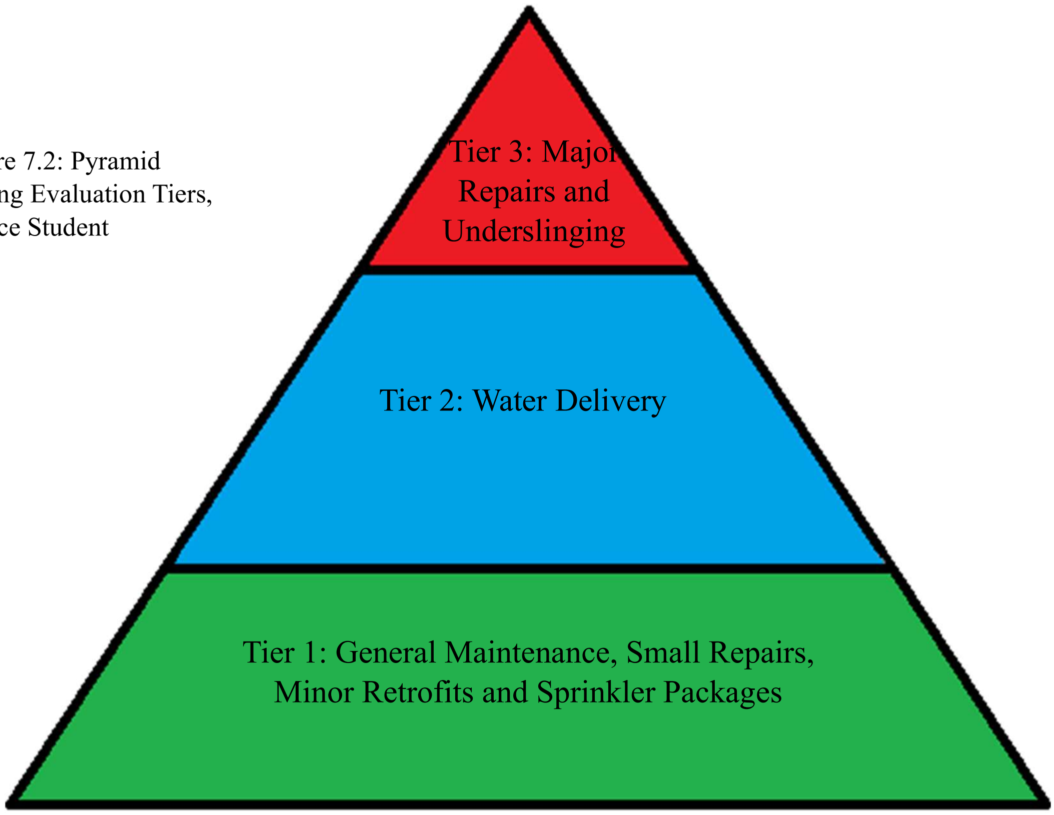
Due to the nature of these machines each system that will be looked at will have their own unique properties and therefore will come with their own set of challenges but as stated before there will be a pyramid tier system that will be used to evaluate the irrigation systems. Each tier of this system will be based on a percentage based on the initial investment required to install the system originally. As giving a hard number on when a machine moves from one tier to another will depend on the size of the machine as a large repair on a smaller machine my only end up costing as much a smaller upgrade to a larger machine.

The lowest of these tiers will be up to 25 % of the initial investment and this tier will be on general maintenance, small repairs, minor retrofits and sprinkler packages. So, in regards to maintenance this will be on the costs of replacing the mechanical components such as the centre drive motors and gear boxes as well as electrical contactors. There two main reasons by observation why these components fail is either by water getting into the electrics and causing a short or being parked up for an extended period of time. Because if a machine is sat in one place for extended period of time the tires on the machine will perish due to prolonged exposure to the sun. One of the other parts that is affected by sitting is the contactors in the tops of each tower that turn the motors on and off as these will corrode and create bad connection causing the motor to stop and pull the machine out of line. Each of the drive line components cost between 900 and 1300 dollars depending on the make and model, (Pivot Irrigation Australia Pty Ltd, 2022). The tires cost 1000 dollars fitted with a rim and the contactors are about 30 dollars apiece and these costs are usually occurred after long periods of time not in use or have just reached the end of their working life (Pivot Irrigation Australia Pty Ltd, 2022). The sprinkler package if the only thing that is going to be replaced is the nozzle and the body of the sprinkler is reused this cost from 3-6 dollars depending on the brand and any price break that the sales representative passes onto the customer, (Nelson, 2023). The last part of this tier is minor cosmetic updates, one that sticks out here is the installation of new control panel and this cost from 5000-7500 dollars depending on the brand, (Pain, 2023).

The second tier is on water delivery in this tier is the pipe work and the pumps these are together in this tier as this is where large amounts of money can be spent on the system due to the cost of the labour and components required to install them and this tier will go up to 50% of the initial investment. Also, these components are in this tier as due to the feasibility of digging up to water mains and pulling up pumps these are usually done in conjunction with a upgrade to the sprinkler package as there is now more water at the disposal of the producer. Times where replacing the water mains are also usually done with the acquisition of more water this can be through buying more river allocation or by deepening or drilling of a new bore therefore leading to more water being pushed down the pipeline. As such upgrades of this nature are not that common.

The third and final tier of the pyramid is base on the machine its self, as when a machine is aging and starting to corrode and leak and from here there are three opinions, the first is to re-pipe the machine this involves taking the machine apart and is the machine is poly lined installing new poly or in case where epoxy or no coating is used new pipe which in turn means installing new structural members to the machine and this is a costly exercise as other than installing a new machine can cost upwards of 75% of the initial investment of the machine and is usually avoided due to the cost of this process. Second as mentioned if the machine is nearing its end of life sometimes it is more beneficial to opt for a new machine and pull the old one down. The final option is to run a new main line under the original one and the original is used only as a structural member and the sprinklers run off the new main line which in now underneath, this process is known as under slinging the machine and is a way to still use the original structure of the machine and extend the life of the machine for much less capital than the first two.

Figure 7.2: Pyramid Pricing Evaluation Tiers, Source Student



Chapter 8 Conclusions

8.1 Future Works

Some future works the first is to investigate the application efficiency and uniformity of centre pivots and lateral moves as of the 3 machines that where observed the crop that was planted beneath them had less height and volume on the first two spans from the centre and after crossing over into the third span the crop was visibly more vibrant and had more volume of fodder growing there. To go into more depth here would require a large amount of data collection from multiple different systems to find the root of this observation could be and would involve a more in-depth look at the uniformity as mentioned in chapter 7.1. Another future work would be to collect more data on the friction loss in the pipe lines and determine how much of an impact elbows and tee joint have on the head losses as well as head losses due to the changes in elevation.

Figure 8.1: Stockhome Second Span, Source Student

Chapter 8.2 Evaluation Test Run

After development of the checks and the pyramid pricing evaluation the Stockhome centre pivot will now be taken through the process to evaluate the system.

The data that is collected from this machine has already been recorded in chapter 6.1and these will be used for the data required in the hydraulic checks so these can be ticked off. Next comes the visual checks figure 8.1 show the second span of the Stockhome machine and here we can see that the centre drive motor has bee replaced and the other 5 on the machine have had their oil changed in both the gear boxes and drive motors. Picture to the right in figure 8.2 that around some of the lines to the sprinklers have started to corrode the machine due to leakages around this line and further down the machine some of two of the lines have popped out of the main line due to corrosion around the grommets the hold the line in place. The tries are in acceptable condition and the sprinkler

Figure 8.2: Corrosion on the Main Pipeline, Source Student

package puts on 5 mm per 24 hours. There are two ways that can come from putting this machine through the pyramid pricing evaluation one is to retrofit the machine with a new sprinkler package but due to the corrosion on the machine the second option is the under sling this machine in conjunction with a new sprinkler package, as with a new sprinkler package installed on this machine will also help with applying more water per 24 hours to enable this machine to do on rotation irrigation events even in the height of summer due to the machine higher application rate. The application rate that is recommended in this area to operation through summer is upwards to 10 mm to stay in front of the evaporation rate in these months. Therefore, the recommended path forward for this machine is to install an underslung pipe with a new sprinkler package until such time that a new machine is installed.

Chapter 8.3 Conclusion

Over the course of the dissertation the aims that have been achieved are developing an initial set of checks as well as a pricing evaluation structure to aid both the producer and the sale representative, even though the producer is going to benefit the most for both of these to aid them in their decision making on what they are going do with their machine. With more time and data I would like to improve upon both of these systems to make a better approach that take into account the uniformity of the machine for one and make these approaches better so that they have more uses by sales representatives.

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Appendix A

University of Southern Queensland	Offline Version

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	ENG 4111	Assessment Date:	2/6/202
Workplace (Division/Faculty/Section):	School of Engineering and Built Envionment	Review Date:(5 Years Max)	30/06/2023

Context			
Description:			
What is the task/event/purchase/project/procedure?	Data Collection for the use in ENG 4111 and ENG 4112 Research Project		
Why is it being conducted?	To collect data on the operations of a center pivot		
Where is it being conducted?	'Fairvale','Woodlands' and 'Stockhome' Malmoe QLD 4627		
Course code (if applicable)	ENG 4111/4112	Chemical name (if applicable)	
What other nominal conditions?			
Personnel involved	Darcy Mossman (Student), Keith Mossman (Owner) and Ernie Evens (Supervisor)		
Equipment	Center Pivots, Submersable pumps, Side-by-Side 4 wheeler, Halmets, simple hand tools to aid with collection.		
Environment	Commersial Irrigation / Grazing Operation		
Other			
Briefly explain the procedure/process	Using the Side-by-side the required persons will go around to each of the noniamted machines to collect the required data points		

Assessment Team - who is conducting the assessment?	
Assessor(s)	Darcy Mossman
Others consulted:	Kieth Mossman

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide

E=Extreme Risk – Task ***MUST NOT*** proceed
H=High Risk – Special Procedures Required (See USQSafe)
M=Moderate Risk – Risk Management Plan/Work Method Statement Required
L=Low Risk – Use Routine Procedures

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Roll over or crash of side-by-side	Ranging for minor grazing to serious injury or loss of life	Catastrophic	Roll-over protection system, training for the operations of vehicle and seatbelts	Possible	High	No	Use of helments and update operating proceedure	Catastrophic	Unlikely	Moderate	Yes
Use of hand tools	Minor injuries including gashes, grases and blisters.	Minor	Long sleeved shirts and enclosed shoes	Unlikely	Low	No	Use of safety glasses and gloves	Minor	Rare	Low	Yes
Prolonged exposure to the sun	Sunburn, heat stoke that could lead to injury	Moderate	Regular breaks, make sure there is water advailible and wear chothing that covers most of your body	Likely	High	No	Supply Sunscreen and areas for shade to be set up.	Moderate	Unlikely	Moderate	Yes
Driving to the data collection sites	Long driving times, causing driver fatigue	Catastrophic	Having a addiquite night of rest before hand.	Unlikely	Moderate	No	Take breaks from driving every 2 hours	Catastrophic	Rare	Low	Yes
		Insignificant		Rare	Low	No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Unable to collect data due to weather	Due to rain and or flooding not being able to get to the data collection site.	Minor	Choose data sites that are unlikely to be compremised due to weather	Possible	Moderate	No	Select a set of data sites that are unlike to be comprmised due to the weather.	Minor	Unlikely	Low	Yes
Exposure to wildlife	Bitten by poisous animals	Major	Remain vigilant and be on the look out for animal	Possible	High	No	Work with in a pair or group	Major	Unlikely	Moderate	Yes
		Major		Unlikely	Moderate	No	Work with someelse and under supervision of them	Major	Rare	Low	Yes
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
Helmets for side-by-side	Motorbike helmets	Darcy Mossman and Keith Mossman	16/06/2023
Gloves and eye protection	Gloves and Safety Glasses	Keith Mossman	16/06/2023
Sunsceen	Sunsceen	Darcy Mossman	16/06/2023
Shaded areas for break	Shade Tent or or onsite shed	Keith Mossman	16/06/2023
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.

Step 6 - Approval			
Drafter's name:		Draft date:	Click here to enter a date.
Drafter's comments:			
Approver's name:		Approver's title/position:	
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.