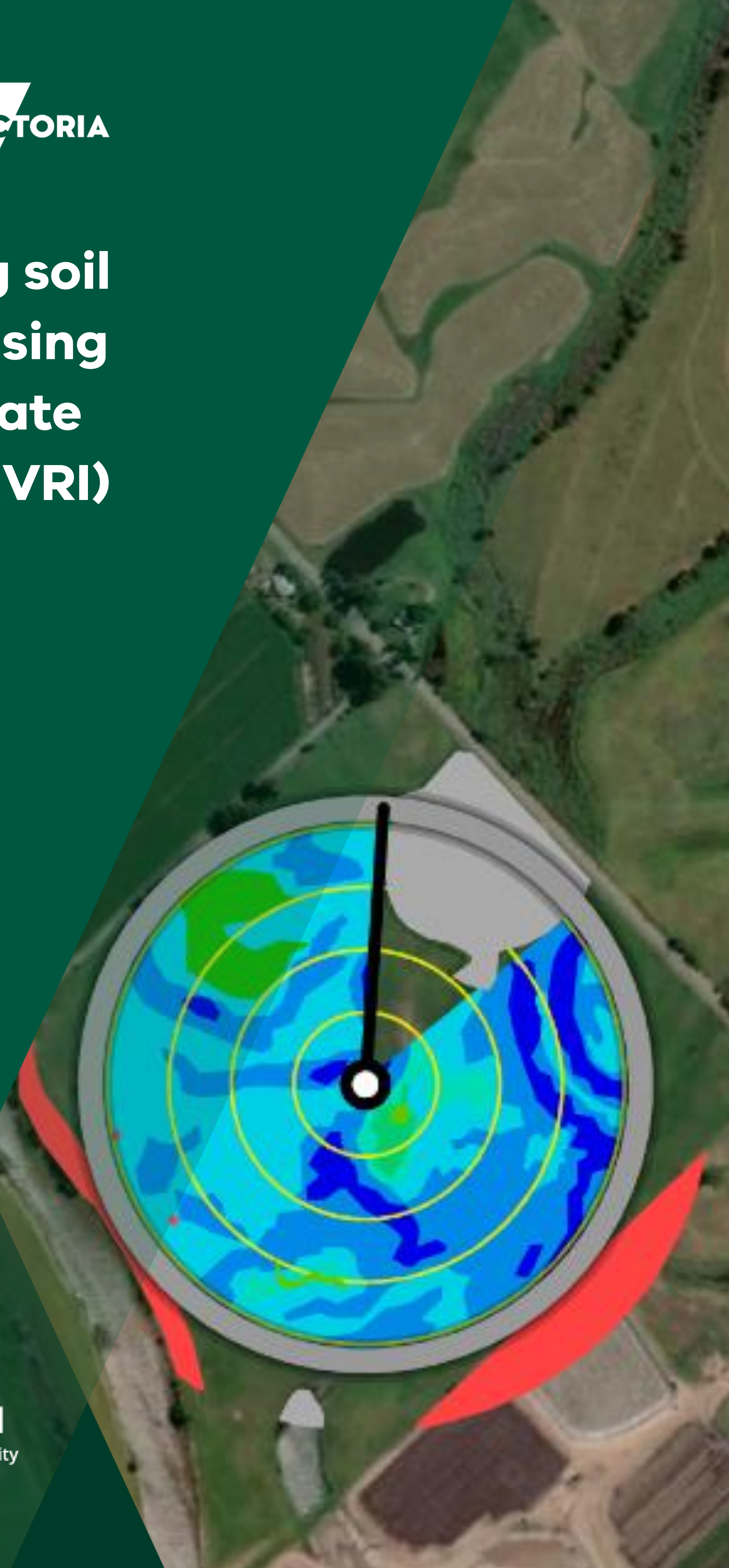
AGRICULTURE VICTORIA

Optimising soil moisture using Variable Rate Irrigation (VRI)



West Gippsland
Catchment Management Authority

Executive summary

A demonstration project was conducted from June 2022 to December 2024 in the Macalister Irrigation District (MID), to evaluate the efficacy of variable rate irrigation (VRI) when applied to a centre pivot irrigator on undulating terrain, for the purpose of reducing waterlogging and increasing soil moisture uniformity.

The paddock selected had significant terrain undulation and highly variable soil moisture across the paddock. There were also areas with little to no drainage that have historically remained wet all year round. Winter rainfall caused waterlogging in these areas, with the addition of irrigation in summer and spring prolonging the waterlogging issues (Figure 1).

Figure 1: *Mapped low area prior to VRI 19-07-22*

VRI technology allows for each sprinkler to apply varying rates of water as required to different zones, allowing irrigation application rates to match water requirements.

A VRI prescription of irrigation water application rates was developed using elevation and EM38 soil type mapping (Figure 2). The prescription programs the VRI technology to apply variable amounts of irrigation water, relative to the topography and soil type of specific locations within the paddock.

Spray system assessments were conducted pre and post installation of VRI technology to assess the irrigation accuracy of the system. Soil moisture probes were installed in areas mapped as wet, moderate, and dry to monitor changes in soil moisture across the variable zones. Photographic monitoring points were established to document any change to the major problem areas and seasonal water use data was collected via the pivots VRI controller.

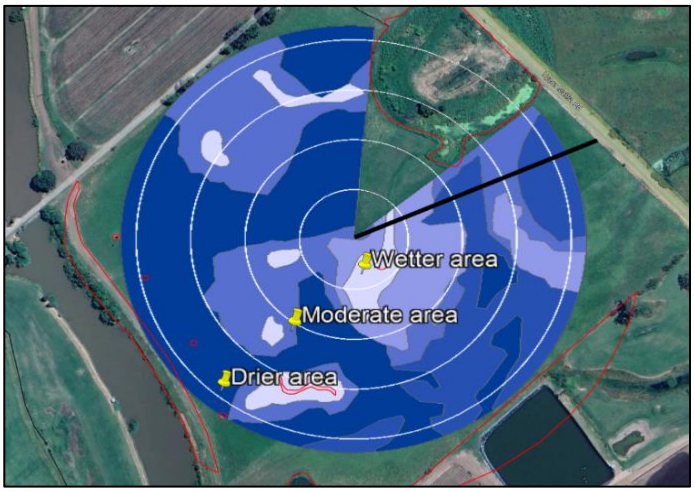


Figure 2: *Irrigation prescription from EM38 and elevation mapping 29-08-22 - Darker areas represent drier zones requiring more water*

The VRI technology used in this demonstration was found to be highly accurate, up to 95% relative to the prescribed amount for any given zone (Figure 3).

Under the conditions of the demonstration, it was found that VRI without added drainage was able to ameliorate waterlogged areas in periods of little to no rainfall, with a dry off period of 2-3 months (Figure 19). The addition of drainage reduced the dry off period of waterlogged areas to 7-14 days, even after a flooding rainfall event (Figure 20).

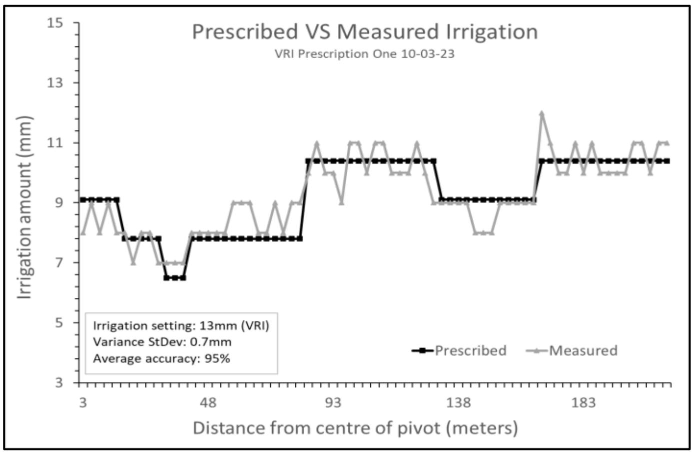


Figure 3: *Spray system assessment 10-03-23 with VRI on prescription one*

Soil moisture probe data showed that VRI paired with EM38 soil type and elevation mapping was able to increase soil moisture uniformity across the wet, moderate and dry zones within the paddock (Figures 19 – 24). This was confirmed when comparing the total areas for wet, moderate and dry zones between the EM38 and elevation VRI prescriptions (Table 1).

An estimated 11.4ML of water was saved using VRI in the 2022-2023 irrigation season, an 18% saving relative to conventional irrigation. The estimated water savings for 2023-2024 is 16ML, a saving of 26% relative to conventional irrigation (Tables 2-4).

Figure 4: *Mapped low area dried under VRI 04-09-23*

It was concluded that VRI paired with EM38 and elevation mapping was effective at increasing soil moisture uniformity on undulating terrain while additional drainage was required to maintain waterlogging amelioration in some problem areas (Figure 4).

Methodology

VARIABLE RATE IRRIGATION (VRI)

A precision variable rate irrigation system was installed on the centre pivot irrigator. VRI technology allows for each sprinkler to apply varying rates of water as required to different zones, which can include turning on and off over physical assets such as laneways on farms.

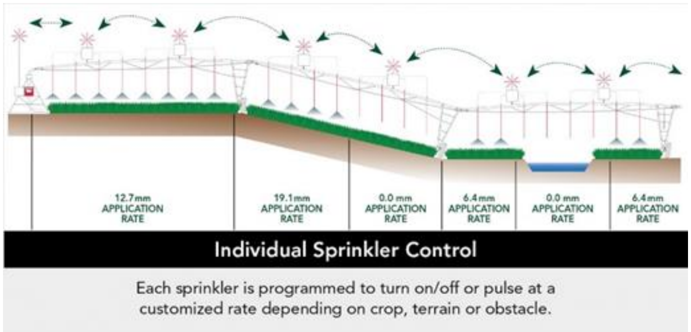


Figure 5: *Illustrating individual sprinkler control of VRI*

This system includes GPS nodes and controllers on each pivot tower and solenoid controls on each individual sprinkler outlet (Figure 5). The GPS nodes allow the VRI controller to know the exact location of each sprinkler in the paddock at any point in time, while the solenoids allow pulse control of flow to alter the application rate.

For example, sprinklers in a 50% application zone will turn on and off to achieve 50% sprinkler on time. If the master irrigation setting is 13mm, then these areas should receive 6.5mm.

SPRAY SYSTEM ASSESSMENTS

Spray system assessments were conducted to evaluate the application efficacy pre and post installation of the VRI technology.

Figure 6: *partial transect of catch cans*

A transect of the pivot footprint was selected to conduct an application assessment (Figure 7). Catch cans were placed at intervals of 3m along this transect, starting at the centre of the pivot (Figures 6 and 7). Pressure gauges were installed on sprinkler outlets on the first and last span to monitor pressure along the system. The pivot was set to irrigate at a specified application rate and allowed to fully pass over the transect of catch cans. The amount captured in the catch cans was recorded and compared to specified application rate.

During the first assessment several sprinkler outlets malfunctioned or blocked, and issues with fluctuating pressure readings were observed. The fluctuating pressure issues were addressed, malfunctioning / blocked sprinklers replaced or cleaned, and another assessment conducted.

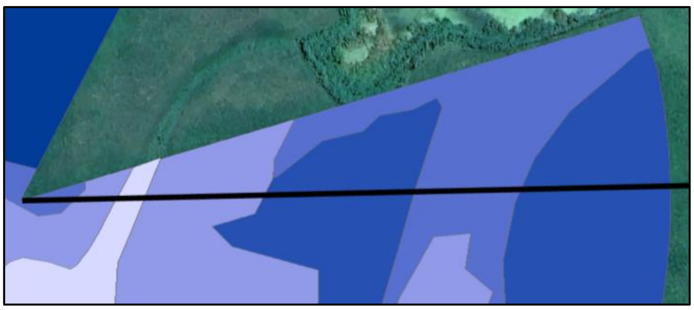


Figure 7: *Prescription zones along catch can transect - Lighter areas lower % applications zones, darker areas higher % application zones*

Further spray system assessments were conducted after the VRI system was installed and after each irrigation prescription was loaded into the controller. The same methodology was applied, however the catch can values were compared to the prescribed percentage application rate for each location rather than the master irrigate rate (Appendix i – Spray system assessment data). For example if the master setting was 13mm a catch can in a 50% applicaion zone would be scored against an expected value of 6.5mm.

EM38 AND ELEVATION VRI PRESCRIPTIONS

A service provider was engaged to conduct two EM38 and elevation maps of the paddock, providing VRI prescriptions to be loaded into the VRI controller (Figure 8). One of these maps was generated on the 29-8-22 (prescription one), pre installation of the VRI system. The second map was generated on 25-8-23 (prescription two) after a full irrigation season of VRI.

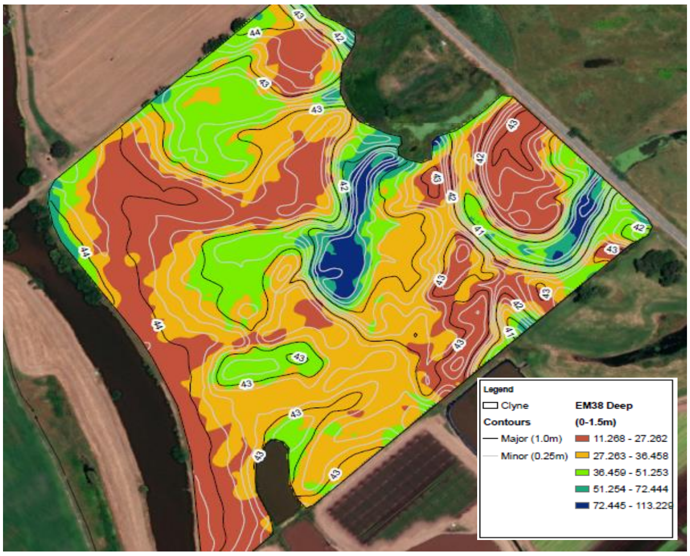


Figure 8: *EM38 and elevation map one 29-08-22*

EM38 surveys involve a vehicle towed sensor that is used in the field to measure electrical conductivity (EC) in the soil at designated depths. Electrical conductivity is primarily influenced by soil texture, in particular clay content, soil salinity and moisture levels.

The EM38 data is combined with elevation to generate a spatial layer that provides zoning for the VRI prescription based on the soil type and topography of the paddock (Figure 11). From this mapping, water flow and proposed drainage maps were also generated (Figures 9 and 10).

Figure 9: *Water flow map one 29-08-22*

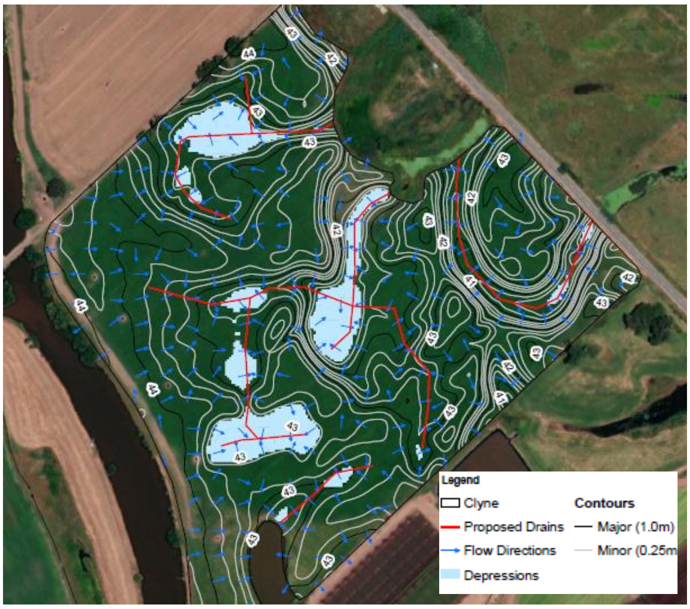


Figure 10: *Proposed drain map one 29-08-22*

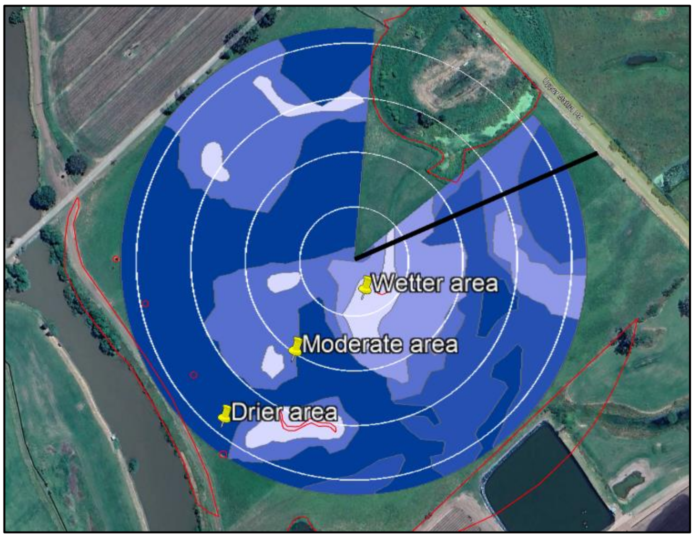


Figure 11: *VRI prescription zone map one 29-08-22*

SOIL MOISTURE MONITORING

Three 60cm soil moisture probes were installed, one in each of the wet, moderate, and dry zones within the paddock (Figure 11). The probes have individual sensors every 10cm allowing a reading for each 10cm profile of soil (Figure 12).

The data from these moisture probes will be used to help in making decisions to irrigate the paddock as well as monitoring any relative changes between the different mapped zone.

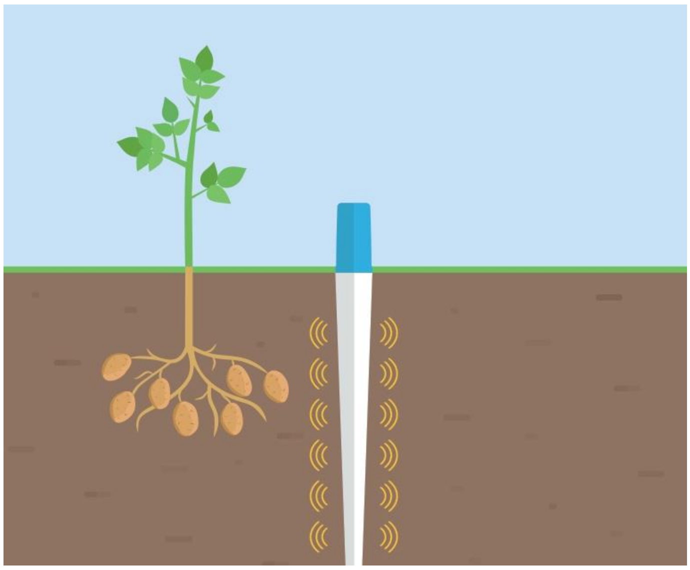


Figure 12: Diagram of *soil moisture probe installed and sensors*

WATER USE

The pivot controller records accurate data on every application including the areas irrigated, how much water went through the pivot, and if partial segments of the pivot were irrigated more than others. The VRI controller on the other hand only records the amount of total water applied to an area and does not provide information on actual volume through the pivot or any information on which areas were irrigated more times than others.

The original methodology for assessing water use was to interrogate the pivot controller data to get a highly accurate measurement of how much water was applied to each area of the pivot and compare that with conventional irrigation. However, during the project a pipeline was installed across a corner of the pivot. During these works the pivot was accidentally walked onto a pile of fill from the pipeline trench and fell over causing severe damage to the pivot (Figure 13).

Figure 13: *Pivot tipped over and severely damaged 17-03-23*

The landowner decided to replace the pivot rather than repair it and in doing so, the pivot controller was replaced. The data that was stored within the controller, and required for the initial assessment method, was lost when the pivot controller was replaced.

Following this incident, a new methodology was devised using data from the VRI controller (Figure 14). This data showed that areas within the 100% application zones received an average of approximately 500mm, equivalent to 5ML for the 2022-2023 irrigation season (Figure 4). This figure was used as the baseline estimate for conventional irrigation over the season.

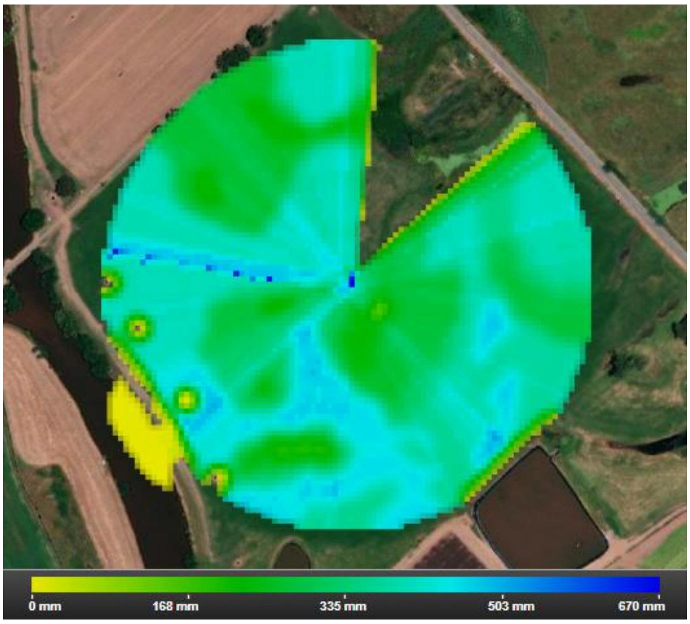


Figure 14: *VRI application depth map* - period reported from 15-08-22 to 15-05-23

There were areas that received higher annual depths, up to 670mm or 6.7ML. However, these areas were considered likely to have received more irrigation passes due to proximity around common stop points of the pivot.

From the prescription mapping, the area for each zone was reported. Each of the zones received a relative % of the master irrigation setting which was assumed at 5ML for the season. The zone areas were multiplied by 5ML and then by the percentage multiplier for that zone. The figures were added together to give a total estimate applied under the two prescriptions developed.

Results

SPRAY SYSTEM ASSESSMENTS

Analysis of the data from the first pre VRI spray system assessment found that there was great variation in application rates along the length of the pivot. The pivot was set to apply 13mm of irrigation, with results indicating an average accuracy of 75% relative to this (Figure 15). There were readings as high as 21mm and as low as 7mm, indicative of the malfunctioning and blocked sprinklers that were noticed.

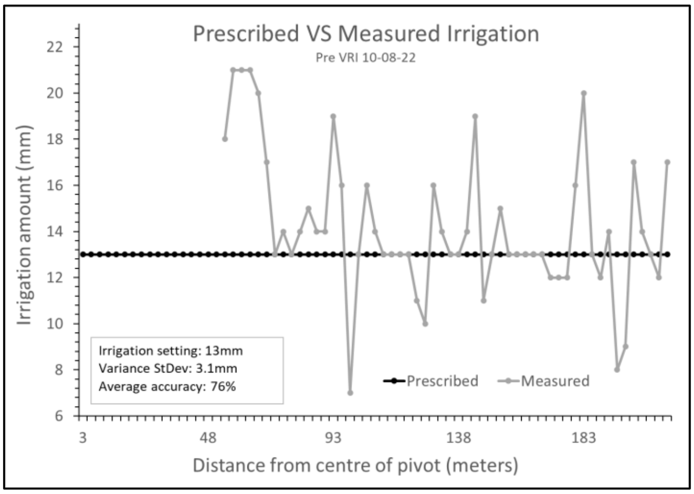


Figure 15: *Spray system assessment pre VRI installation 10-08-22*

After fixing the fluctuating pressure issues and cleaning or replacing the malfunctioning and blocked sprinklers, the application accuracy was greatly increased. The second assessment, pre VRI, found an average accuracy of 93% relative to the 13mm setting, with maximum reading of 15mm and minimum reading of 10mm (Figure 16).

The spray system assessment with VRI installed and set to 100% (all areas of the paddock receive 100% of the master irrigation setting) found that the irrigation accuracy was maintained, with an average accuracy of 93%. The output tended to be slightly higher with the VRI installed, with a maximum of 16mm and minimum reading of 12mm (Figure 17).

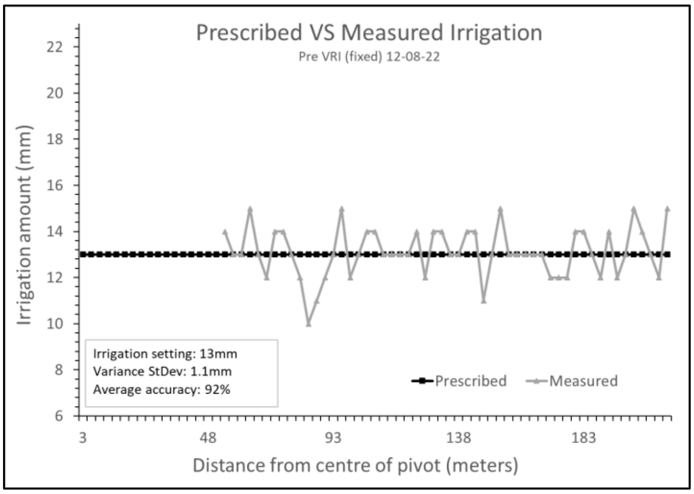


Figure 16: *Spray system assessment pre VRI, post fixing sprinklers 12-08-22*

Analysis of the data collected from the spray system assessment using VRI prescription one found that it was highly accurate relative to the expected values for each zone. The transect of catch can readings was compared against the VRI prescription map to determine what % of the total setting each area should receive. It was found that the recorded application volumes were on average 95% accurate to the expected volume of any zone (Figure 18).

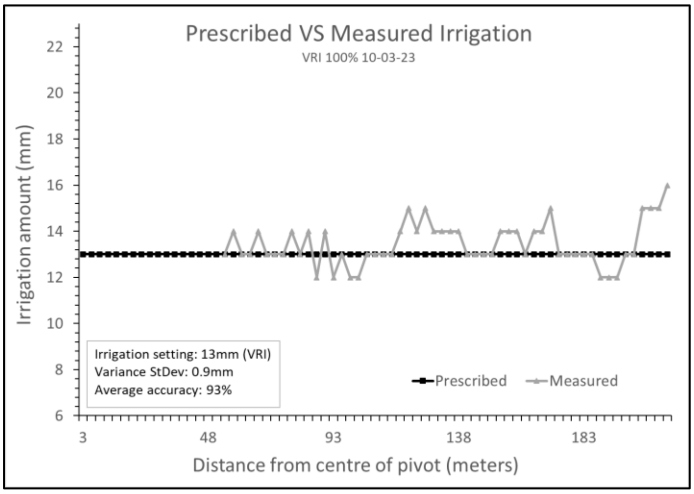
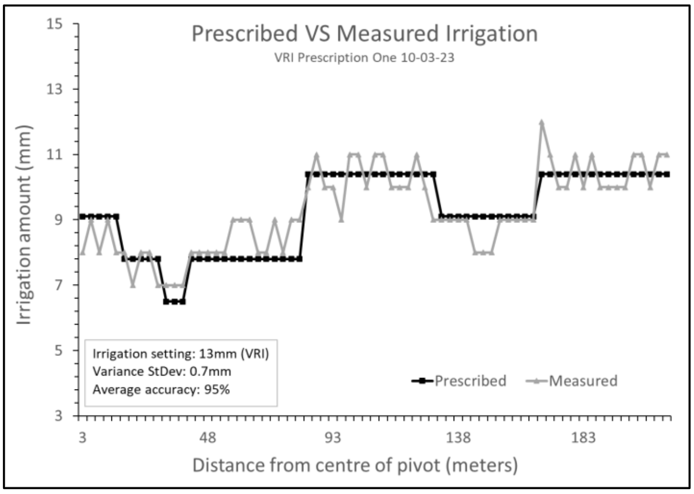


Figure 17: *Spray system assessment with VRI, set at 100% 10-03-23*

The final spray system assessment was conducted under VRI controlled by the second prescription map. It was also found to be highly accurate relative to the expected output for any zone, with the average accuracy found to be 95% relative



to the expected output (Figure 19).

Figure 18: *Spray system assessment with VRI on prescription one 10-03-23*

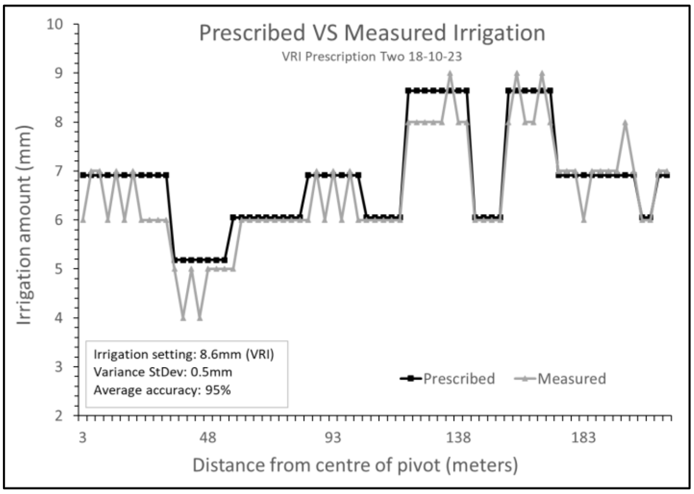


Figure 19: *Spray system assessment with VRI on prescription two 18-10-23*

EM38 AND ELEVATION VRI PRESCRIPTIONS

Assessment of VRI irrigation prescription one found that initially 41% of the pivot area was categorised zone 5 (dry) requiring 100% irrigation, while 18% and 24% respectively was categorised in zones 4 and 3 (moderate) (Table 1). The wet areas categorised as zone 1 accounted for 6% of the pivot area at this time.

Assessment of VRI irrigation prescription two, after a full irrigation season using prescription one, showed that 8% of the pivot area was categorised as zone 5 (dry), while 33% and 45% respectively were categorised in zones 4 and 3 (moderate). Only 1% of the total pivot area as mapped as zone 1 (wet) at this time.

Table 1: *Zone areas for VRI prescriptions*

		Prescrption One		Prescription Two	
VRI Zone	Multiplier (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
1	50	0.8	6	0.2	1
2	60	1.3	10	1.6	12
3	70	3.1	24	5.6	45
4	80	2.3	18	4.2	33
5	100	5.1	41	1.1	8
Total		12.5	100	12.5	100

100% = dry zones requiring full irrigation
50% = wet zone requiring less irrigation

SOIL MOISTURE MONITORING

Analysis of soil moisture probe data in the monitored wet area under VRI prescription one found that the 10cm soil profile was at approximately 50% volumetric water content (VWC) in early September 2022, high level saturation (Figure 20). This level of soil moisture maintained for nearly three months, with a sharp decline in soil moisture observed in late November.

Short lived spikes in soil moisture in the 10cm profile were observed following rainfall events of 17mm and 6mm in December 2022 (Appendix iv – Rainfall data Newry BOM weather station). It was observed that 20cm and 30cm profiles remained in saturation during this period.

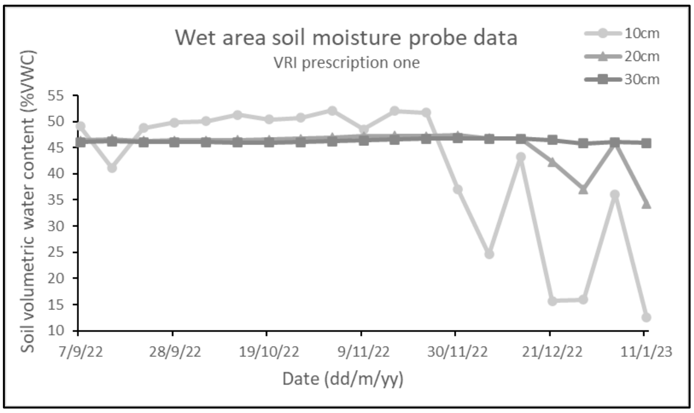


Figure 20: *Soil moisture data – wet area*

Under VRI prescription two with recommended drainage installed it was found that the dry off period in the monitored wet area was significantly reduced. On 5 September 2023 18mm precipitation was recorded (Appendix iv – Rainfall data Newry BOM weather station), resulting in a rise from 40% VWC to 50% VWC (Figure 21). A steep dry off was observed with 40% VWC achieved 20 days later.

Flooding rainfall of 150mm was recorded on 4 and 5 October resulting in an increase from 30% VWC to 50% VWC. Again, it was observed that 40% VWC was achieved in only 20 days after this rainfall event. It was observed that 20cm and 30cm profiles remained in saturation up until late October 2023, where a reduction to 30% VWC was recorded.

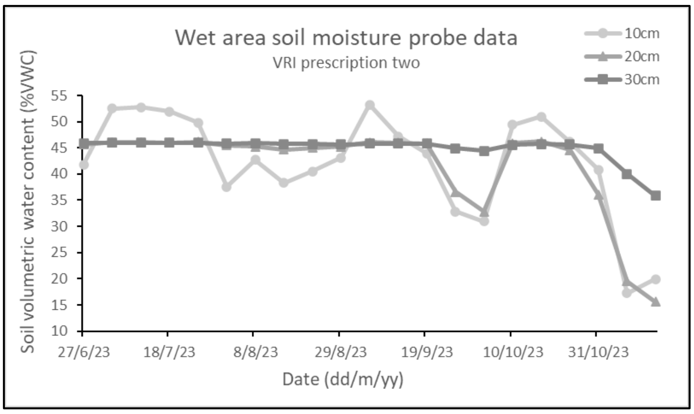


Figure 21: *Soil moisture data – wet area*

In the monitored dry area it was observed that the initial soil moisture in 10cm profile was 25% VWC (well into pasture stress levels) (Figure 22). It was observed that under prescription one, by mid-October 2022 soil moisture was about 35% VWC. However, there was significant fluctuation in this level between 25-35% VWC, slightly lower than the ideal for this soil of 30-40% VWC. It was observed that the 20cm and 30cm profiles, while remaining relatively stable, did tend to increase in soil moisture from around 38% VWC up to 40% VWC.

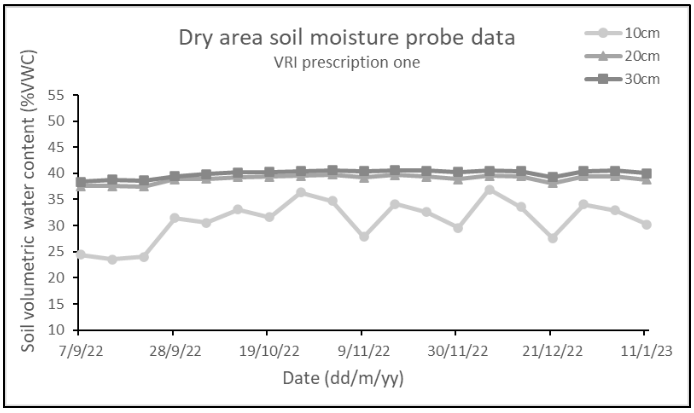


Figure 22: *Soil moisture data - dry area*

Under prescription two it was observed that the 10cm profile remained well within the ideal range of 30-40%V VWC from late June to November 2023 (Figure 23). It was also observed that the 20cm and 30cm profiles remained stable around 40% VWC across this assessment period.

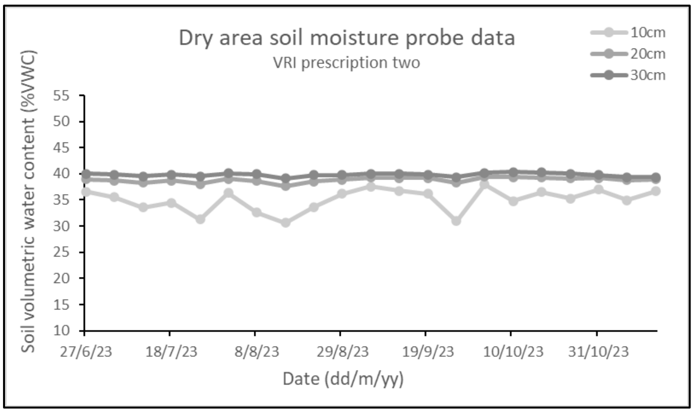


Figure 23: *Soil moisture data – dry area*

In the moderate area under prescription one it was observed that 10cm, 20cm and 30cm profiles all fluctuated in soil moisture across the assessed period (Figure 24). 10cm and 20cm profiles were at 35% VWC in early September 2022, while the 30cm profile recorded 40% VWC.

By early November 2022 the 10cm and 20cm profiles were around 40% VWC while the 30cm was up to around 50% VWC. By early January 2023 soil moisture levels had dropped significantly, with 10cm recording 25% VWC while 20cm and 30cm recorded 30-35% VWC.

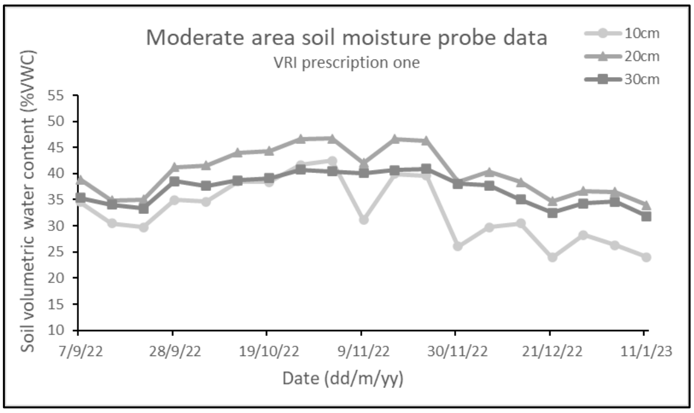


Figure 24: *Soil moisture data - moderate area*

Under prescription two it was observed that the moderate area maintained soil moisture levels within the ideal range of 30-40%VWC (Figure 25).

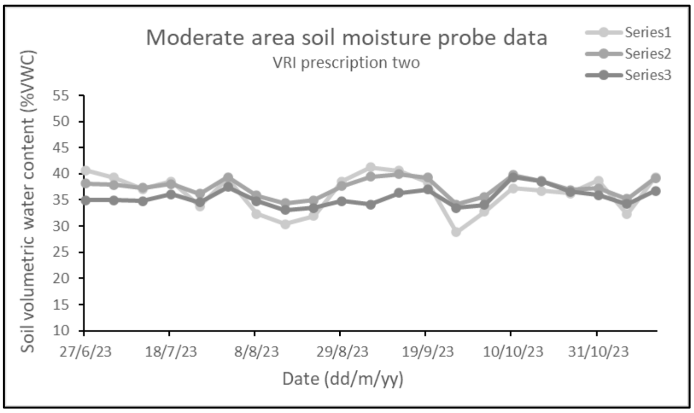


Figure 25: *Soil moisture data – moderate area*

At the end of June 2023, the 10cm profile recorded 40% VWC while the 20cm and 30cm profiles recorded 38% and 40% respectively. There was observable fluctuation with 10cm profile dropping as low as 28% VWC but tending to stay between 30-40% VWC.

WATER USE

Assessment of seasonal water use output from VRI controller indicated approximately 500mm application in zones of 100% application (Figure 14). On this assumption, without VRI the 12.5ha pivot would have applied 62.5ML of water over the irrigation season (Table 2).

Table 2: *Estimated 2022-2023 irrigation season water use without VRI installed or VRI set to blanket 100%*

No VRI - 100%

Season irrigation volume at 100% (ML/ha): 5

VRI Zone	Multiplier (%)	Area (ha)	Area (%)	Applied (ML)
1	50	0.0	0	0.0
2	60	0.0	0	0.0
3	70	0.0	0	0.0
4	80	0.0	0	0.0
5	100	12.5	100	62.5
Total		12.5	100	**62.5**

Season irrigation volume derived from VRI seasonal irrigation depth map estimated for areas of zone 5 (100%).

Table 3: *Estimated 2022-2023 irrigation season water use with VRI under prescription derived from initial EM38 and elevation mapping*

VRI Prescription One

Season irrigation volume at 100% (ML/ha): 5

VRI Zone	Multiplier (%)	Area (ha)	Area (%)	Applied (ML)
1	50	0.8	6	2.0
2	60	1.3	10	3.9
3	70	3.1	24	10.7
4	80	2.3	18	9.0
5	100	5.1	41	25.5
Total		12.5	100	**51.1**

Season irrigation volume derived from VRI seasonal irrigation depth map estimated for areas of zone 5 (100%).

In contrast under prescriptions one, only 5.1ha would receive 100% irrigation rate, while 2.3, 3.1, 1.3 and .8 ha would have received 80, 70, 60 and 50 % application rates respectively (Table 3 and Figure 26). This would have led to estimate seasonal irrigation delivery of 51.1ML, a saving of 11.4Ml or 18% over conventional irrigation.

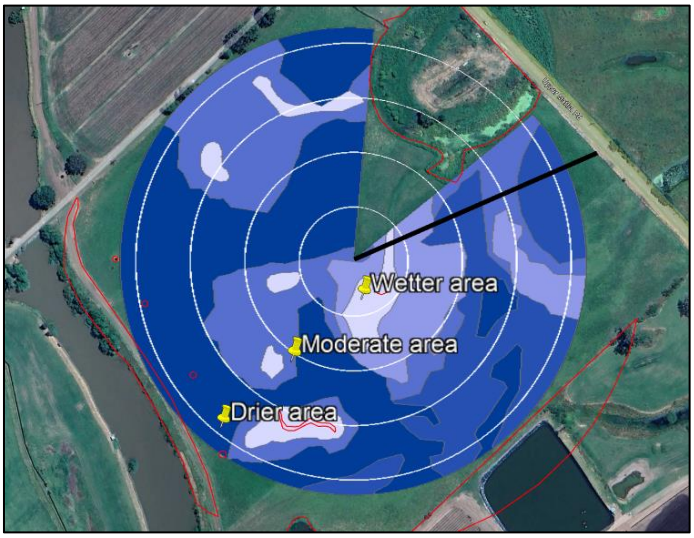


Figure 26: *VRI prescription one from EM38 and Elevation mapping 29-08-22 – darkest areas are zone 5*

Furthermore, analysis of irrigation prescription two found that only 1.1ha would require 100% application rate, while 4.2, 5.6, 1.6 * 0.2 ha would have received 80, 70, 60 and 50 % respectively (Table 4 and Figure 27). This is estimated at a season irrigation delivery of 46.5ML, a saving of 16ML or 26% relative to conventional irrigation.

Table 4: *Estimated 2022-2023 irrigation season water use with VRI under prescription two derived from second EM38 and elevation mapping*

VRI Prescription Two

Season irrigation volume at 100% (ML/ha): 5

VRI Zone	Multiplier (%)	Area (ha)	Area (%)	Applied (ML)
1	50	0.2	1	0.4
2	60	1.6	12	4.7
3	70	5.6	45	19.5
4	80	4.2	33	16.6
5	100	1.1	8	5.3
Total		12.5	100	**46.5**

Season irrigation volume derived from VRI seasonal irrigation depth map estimated for areas of zone 5 (100%).

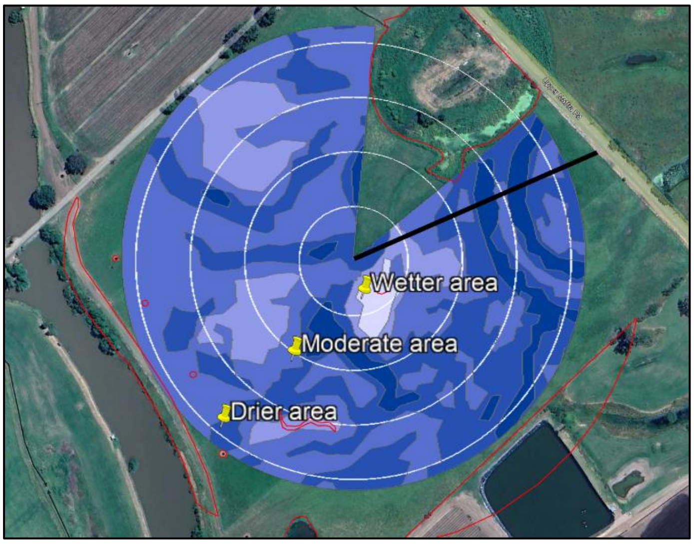


Figure 27: *VRI prescription two from EM38 and Elevation mapping 25-08-23 – darkest areas are zone 5*

Discussion

The initial pre VRI spray system assessment conducted on the pivot highlighted how inaccuracies develop within spray systems over time (Figure 15). A very low average accuracy of 76% was recorded relative to the 13mm setting. In some areas as little as 7mm was applied while up to 21mm was applied in others.

There were pressure variances due to an incorrectly set end-gun pump, this issue was amended, along with replacement of broken sprinklers and hoses, and cleaning of all sprinklers. After this system maintenance, 93% accuracy was achieved.

This is a good example and reminder to all irrigators, to conduct annual system assessments, checking for leaks or malfunctions, cleaning sprinklers, and checking output of the infrastructure.

The VRI system was found to be highly accurate relative to the prescription developed from EM38 and elevation mapping (Figures 17-19). The system varies the percentage on time of sprinklers relative to their location in the paddock and the corresponding prescription zone. It was shown that across both prescription one and two that there was 95% accuracy relative to the expected amount in any particular zone.

Due to the high level of accuracy achieved, it was determined that seasonal irrigation volume estimates based upon zone areas and the % irrigation multiplier of these zones would act a good estimate of seasonal water application.

It was found that during the demonstration, VRI alone was sufficient to allow the monitored wet area to dry out (Figure 20). This was a good indicator that the VRI technology was effective at reducing irrigation and runoff into these areas. However, this was only apparent in periods of little or no natural precipitation. On average it tended to take between 2-3 months for these areas to dry off under VRI alone, in a very wet season. Later installation of the recommended drain greatly reduced this dry off period to around 7-14 days, even after 150mm of flooding rainfall (Figure 21). It was therefore determined that the additional drainage was required for an optimal scenario for ameliorating wet areas in this instance.

VRI prescription one was somewhat effective at increasing soil moisture uniformity across the mapped wet, moderate and dry zones within the paddock. However, the dry zone remained slightly under the optimum range, the wet zone took an exceedingly long time to dry out and the moderate zone fluctuated both above and below optimum ranges (Figures 20, 22 and 24). VRI prescription two with the addition of recommended drains was much more effective at increasing soil moisture uniformity across the zones, with much quicker dry off periods in the wet zones and the moderate and dry zones fluctuating within the optimum ranges of soil moisture (Figures 21, 23 and 25).

The added benefit of significant water savings was also achieved utilising VRI in this use case. Approximately 11.4ML of water was saved in the 2022-2023 irrigation season, and 18% saving over conventional irrigation (Tables 2 and 3). The water savings were further estimated to increase to 16ML in the 2023-2024 irrigation season, a saving of 26% (Tables 2 and 4).

This demonstration showed the real potential of VRI technology in this use case. It was concluded that while VRI paired with EM38 and elevation mapping was able to reduce waterlogging, sufficient drainage is still required to maintain full amelioration. Furthermore, semi regular mapping is required to alter the prescription to optimise irrigation as changes in soil moisture occur. Further research studies would be required to confirm the outcomes of this demonstration. Additional financial analysis of the practice and system would be highly beneficial for irrigators to make an informed decision on this technology.

Conclusions

The variable rate irrigation (VRI) technology used in this demonstration was found to be highly accurate, up to 95% relative to the prescribed amount for any given zone (Figure 3).

Under the conditions of the demonstration, it was found that VRI without added drainage was able to ameliorate waterlogged areas in periods of little to no rainfall, with a dry off period of 4-8weeks (Figure 20).

The addition of drainage reduced the dry off period of waterlogged areas to 7-14 days, even after a flooding rainfall event (Figure 21).

Soil moisture probe data showed that VRI paired with EM38 soil type and elevation mapping was able to increase soil moisture uniformity across the wet, moderate and dry zones within the paddock (Figures 20-25).

This was confirmed when comparing the total areas for wet, moderate and dry zones between the EM38 and elevation VRI prescriptions (Table 1).

An estimated 11.4ML of water was saved using VRI in the 2022-2023 irrigation season, an 18% saving relative to conventional irrigation (Tables 2 and 3). The estimated water savings for the 2023-2024 on prescription two is 16ML, a saving of 26% relative to conventional irrigation (Tables 2 and 4).

It was concluded that VRI paired with EM38 and elevation mapping was effective at increasing soil moisture uniformity on undulating terrain, while drainage was required to maintain waterlogging amelioration in some problem areas.