Project Summary

This report is divided into four main sections:

1. The first summerises the key achievements of the Resilient EP project in terms of capacity, practice change and on-farm impacts.

2. The following section focuses on communications and engagement including the role of the Regional Innovators Group (RIG), the discussion groups and the specialist workshops held over the course of the project.

3. The third section focuses on the research and development aspects of the project, including the research on mapping soil available water capacity spatially and temporally across farms, the development of the regional soil water sensor network, the characterisation of soils across the region, the development of the soil water application, the role of the validation field sites (focus paddocks) and Yield Prophet®.

4. The final section summarises the role of project management and what needs to be considered moving on from this project.

Innovation Tour, Wharminda focus paddock site, August 2022

1. Summary of Achievements

Relationships

A strong feature of the project has been the strengthening of relationships between farmers, consultants and researchers. Feedback from engaged farmers and case studies of impact on focus paddock host farmers showed that this interaction provided the basis for a deeper appreciation of how a better understanding of plant available water and the role (and limitations) of forecasts can improve decision-making around crop and fertiliser management for optimal yields.

Engagement and communication

Project awareness was communicated broadly through the region through the AIR EP Newsletter, dedicated website and social media as well as an internal project newsletter called 'The RIG Report' to update those most closely involved with what was happening and coming out of the project. Bi-annual RIG meetings provided a very effective opportunity for interaction with researchers and developing mutual understanding around soil water management. Broader messaging in relation to taking action was dependant on the findings from the project trials, with limited data available in the early to mid-stages of the project – momentum in this area increased in the final year. Project outcomes will continue to impact on available information and advice and inform future projects and communication to farmers.

Discussion groups around the eight validation sites (focus paddocks) proved to be very effective in stimulating interest and discussion around soil moisture and crop management. The EP Innovation tour to validation sites which involved key farming systems scientists and advisers from across Australia was viewed as a very successful way of bridging the gap between farmer and research knowledge, and the Nitrogen Workshop was described as 'one of the best conversations that has ever been had about our biggest [cropping] input - nitrogen'.
Research and development

Research and development

While the intended development of the soil water sensor network did not proceed in the way that was initially envisaged due to technology limitations related to sensors and calibration requirements, the work undertaken was seen to have been successful in improving understanding and use of probes, as well as the challenges and limitations associated with them.

A working product for data visualisation was co-designed and refined by researchers, RIG members, and the product developers. The validation sites were assessed as having added significant value to the project in improving the understanding of technology integration in farming practices and the use of soil moisture probes to make informed decisions. The climate risk team was seen to have successfully supported and liaised with others in the project to improve how climate risk and seasonal forecasts are communicated and understood.

Summary of achievements - planned project outcomes/outputs and achievements against these

Planned Outcome/Output	Extent of Achievement	Comments

Improved understanding of climate risks	Moderate	The project helped participants to understand the climate factors that posed risk to their farm businesses and some steps that could be taken to minimise these.
A better understanding of seasonal climate forecasts	Moderate	Despite some of the forecasts not being consistent with actuals over the course of the project, exposure to climate forecasts, resources and expertise increased the grower understanding of the influences and most effective use of forecasts.
Improved decision making on cropping and grazing management in relation to soil and water.	High	The trials and discussions around plant available water, the role of soil moisture probes and climate forecasts provided a better understanding in engaged growers around the amount and timing of N, control of summer weeds and choice of crops and rotations – as well as the benefits of variable rate application.
Improved profitability	Moderate	Improved decision making around soil moisture and use of N was shown to have a significant impact on optimal productivity and hence profits.
Famers and advisers engaging to work together	High	The RIG approach was a significant factor in the effectiveness of the project and in pioneering how stakeholder input can maximise benefits from projects.
Increased social capital in the EP Farming system	High	All of the different stakeholder groups strengthened their networks, understanding, and social and technical resources for ongoing improvements to their farm and social resilience.
Communications strategy	High	There was good use of communication medium for external and internal stakeholders. The discussion groups proved very effective for those more closely engaged – there was a recognition that there was a need to even better communicate with the broader grower group networks.
Regional Innovators Group (RIG)	High	As above, the RIG was made up of regionally based growers, consultants, and researchers and provided a very effective mechanism for adaptive management.
Field Days/walks at trial sites	High	There were a number of field walks and discussion groups around the host farms with positive feedback about the value from participants.
Decision Support Tools developed/improved	Moderate	CSIRO assisted with the analysis and quality assurance of plant available water characterisations and refined APSIM outputs for the Eyre Peninsula and made them available for project use via Yield Prophet.
Review of soil characterisation	Moderate	As above, soil sampling at all probe sites undertaken to determine crop lower limits.
Soil water probes improved	Moderate	Probes outputs were found to be limited in some soil types and summers readings needed calibration to account for warmer temperatures. CSIRO tested a range of methods for extrapolating soil moisture probe data away from the probe location at paddock and potentially farm (and

		regional) scale. Strength of relationships between soils, PAW, rainfall and probe signals investigated to test reliability of probe signal to soil moisture. Regional gaps in soil moisture probes were identified by the CSIRO and in some instances filled.
User-friendly/mobile application for soil moisture data display	Moderate	Square V delivered a working product that was co-designed and refined multiple times based on RIG feedback – a large amount of time was spent trying to triage data issues caused by the probe hardware. Available on https://probes.airep.com.au/
Maps of production risks based on available soil moisture and production risk.	At farm level	Plant available water (PAW) data used in digital soil mapping to predict PAW across three focus farms at the paddock and farm level. Early project attempts to produce regional real time PAW maps proved to be too difficult due to lack of data.

The project made several significant contributions towards improved understanding and soil management. These are summarised below:

Use of soil moisture probes: Stakeholders reported that the research has helped to better understand the benefits and limitations of using soil moisture probes and resulted in increased accuracy (reduced error to around 20-30mm) of stored water available to plants. Yield Prophet reports, and paddock meetings have increased grower understanding.

Mapping soil moisture: The project aimed to map plant available soil moisture across the landscape and while it did not achieve this project goal, it provided valuable learnings about the limitations and capabilities of available technologies, as well as highlighting the complexities of landscape and farming systems and the importance of understanding paddock variability when making decisions. Techniques for mapping plant available water at the paddock and farm were tested and provided significant direction for future research. The project was seen to have been beneficial for growers and advisers, in lower rainfall areas, "changing their perspective on what they can achieve." Formalized management processes, including PAW maps, have been implemented, including some equipment changes. Adjusting inputs into APSIM have resulted in more accurate Yield Prophet® predictions for the region, critical for tracking production potential throughout the growing season.

Improved soil management: Project research has contributed to improved soil and water management on farms, enabling more informed conversations and decision-making about sowing time and techniques, fertilizer rates, and weed management. It has given farmers greater confidence in making decisions about crop management and monitoring plant available moisture throughout the growing season.

Local Soil Characteristics: An additional 31 soils were characterised across the region which have contributed to the understanding of plant available water. While there are still unanswered questions, the project has contributed valuable information about soil characteristics in the Eyre Peninsula, soil types, reducing expenses on less reliable zones in the paddock and helped farmers understand the impact of soil constraints and reduced rainfall on soil moisture.

Improved understanding of climate risk and seasonal forecasts: The project has led to an improved understanding of climate probabilities, forecasting, and the use of tools including Yield Prophet reports. The impact of climate change on plant available water is better understood, and in-season climate information is being used to inform on-farm decisions. There is also an increased understanding of climate drivers and the available models to aid in decision making.

Improved relationships: The project's structure and the involvement of growers, consultants, and researchers from the onset, was seen as one of the strengths of the project. It was agreed to have successfully linked these different groups across the Eyre Peninsula, bringing them together to discuss regional issues and exchange knowledge. This base is an important one to continue on-going momentum towards achieving the longer-term goals of the project.

Decision-making: The project's goal to improve decision-making and nitrogen management in crops was also seen to have met with some success. Moisture probes were reported to have helped farmers make decisions about efficient fertilizer use and gain a better understanding of their soil characteristics and plant available water. After three years of accumulated data across the Eyre Peninsula, farmers interviewed are more confident in their sowing decisions and have made a good start toward determining potential yield using plant available water data from the probes.

Researcher capacity: From a researcher perspective, the continuity of meetings across the three years was acknowledged as "rare" and "extremely valuable" in discussing weather conditions and forecasts. Challenging growing seasons during 2020 and 2021 also highlighted the importance of using imperfect forecasts and communicating results more effectively.

Capacity, practice change and on-farm Impacts

A strong feature of the project has been the strengthening of relationships between farmers, consultants and researchers. Feedback from engaged farmers and Farmer Case Studies of impact on host farmers for trials showed that this interaction provided the basis for a deeper understanding of how a better understanding of plant available water and the role (and limitations) of forecasts can improve decision making around crop and fertiliser management for optimal yields.

RIG members reported having a better understanding of where current research got to and of farmers' perspectives and the benefit of everyone coming together into one room and provided a platform for discussion. It was seen to have provided opportunities for researchers to directly engage with farmers on the Eyre Peninsula. Although seen as very successful in engaging and providing useful information to those directly involved, its impact on a broader constituency *remains to be seen*.

Improved understanding and decision-making

Stakeholders interviewed as part of the final project evaluation overall believed the project had been quite successful in terms of improving decision making in relation to improved understanding of plant available soil water reserves. RIG members in the final workshop reported a number of impacts of the project on their own decision-making including expanding thinking on what wheat yields were possible; better linking soil moisture to projected yields; altering rotations; better understanding of the limits of extrapolation from a single probe; making decisions around summer weed control; finding the 'sweet spot' for nitrogen decisions; and increased use of variable rate application and technology.

The farmer case studies provide real examples of where the project and its activities have impacted on individual growers. The table below captures the key features of the cases and the impacts on the producers involved. The cases show how involvement in the project validated some current practices, strengthened understanding and lead to confidence and improved practices around variable rate, nitrogen use and reducing risk in crops.

End of project farmer case studies

Case Study	Impact on awareness and understanding	Impact on decision making
Variable rate inputs on variable soil types based on yield potential		
Using moisture probes to understand and manage soil variability across zones, paddocks and whole of farm, to mitigate risk. Bruce Heddle's 1600 hectare cropping focus and livestock – on-farm trial with project – had an existing soil moisture probe	• Understanding the variable plant available water capacity (PAWC) across zones within his paddock has been beneficial with the use of VRT to optimise inputs. With the added knowledge of PAW and use of technology such as the soil moisture probe, yields can be optimised in season. • The EPAG Research team were seen as thorough and disciplined in their process and Bruce places significant value on this data as a resource. • He reported that conversation at farmer group meetings held at the site had been engaging and free flowing with people interested to see what comes of the two replicated trials. He feels the region is gaining a better understanding of the role and limitations of soil moisture probes.	• The Resilient EP project has served to validate his strategies. • His move towards variable rate is happening concurrently with the Resilient EP project trial, "not necessarily as a result of it." - the only major changes being towards variable rate, which have been in response to the zones.
Variable rate technologies across variable soil types and sustainability impacts Todd Mathew's 6500 hectares mixed enterprise cropping peas, lentils, canola and barley as well as running sheep – on farm trial on 180 hectares where there is a high level of variation in yield.	• The main value Todd has gained from his involvement in the project has been a result of the protein machine installed. While this was not the anticipated outcome, it has been worthwhile, and he has gained an added layer of data across his paddocks. • Todd has a better understanding of soil moisture and when to push more inputs, accounting for deep N levels. • Todd believes this project is contributing to improved understanding about soil constraints, different soil types and variability within paddocks and across farms. He said most growers in the district have visited his paddock and had in paddock discussions about nitrogen, which he believes will impact their nitrogen decisions.	• His involvement in the Resilient Eyre Peninsula project has also given him confidence to use variable rate technologies on his farm. • From an environmental perspective he said this knowledge "helps in making more informed decisions and making sure we are efficient." He is hopeful that as a result of his involvement he has locked in some higher yields.
Pushing the Benchmark		
Pushing the Benchmark Kerran's farm 6500-hectare mixed farming enterprise, cropping 4500 hectares and running between 2500	• just starting to get results in terms of understanding nitrogen levels and soil available water to the plant, but suggested more time is needed to understand how that is driving yields and how the nitrogen is cycling through a whole rotation. He said, "while we are always building a better understanding, I feel like we've got a lot more to learn". • He believes the results will be closely looked at locally, as a lot of growers are seriously looking at	• Kerran will be looking at how he can use learnings from the harvest of nitrogen test strips to plan nitrogen inputs more broadly. • He said, "if we can get some good data out of this, and I think it's going to be, then there will be more uptake of variable rate technology to better match nitrogen inputs and be more cost effective. People will see the

Case Study	Impact on awareness and understanding	Impact on decision making
and 4000 Merino sheep - deep N trials across his paddock and the impacts on input costs and yields.	their systems and how much it is costing to put crops in.	benefit if they can see the results in the data."
Stored soil moisture, yield potential and how to mitigate risk		
Understanding stored soil moisture Paul Schaefer's 4,500 ha property livestock as well as barley, canola, vetch, lupins and medic pasture rotations – on-farm mixed farming trial	• The level of information available from the moisture probes was described as unexpected and its value has been "really excellent." In the past he did not often make changes to set plans, whereas now armed with this type of information he would "base rotations on the moisture available rather than just a guess." Previously, Paul said he had been caught out, letting pasture die off. He explained that having the two probes on paddocks, side by side, has shown that a wheat crop once it is ripe, stops using moisture, but the pastures can continue draining moisture for a long time, sometimes into January, which means a lot of moisture is needed to recharge the system. • Paul is more likely to spray pastures out earlier, even if there is some feed left, to conserve moisture. "This was something that we thought we knew we needed to do but didn't do as much as we should have in the past," he said.	• The moisture probes have given Paul confidence to do summer weed control, knowing that money spent on summer spraying is beneficial. He explained that after spraying a paddock and reviewing the probes data, several days later, he can see moisture has stopped draining out the soil profile. The moisture probes have given him confidence to make these decisions. • In terms of long-term planning, Paul is hoping to re-introduce canola back into his system after not sowing it for several years. He explained canola had generally been a risky crop in the region and has not been a huge part of his rotations. With the data from his moisture probe, he now has the confidence pre-sowing, to better understand available soil moisture.
Using soil moisture data to make targeted decisions relating to inputs and yield potential Andrew's 8,000 ha property principally cropping wheat and lentils, as well as barley, canola and faba beans.	• Andrew has gained a lot of insight about his soil type and how to manage his paddocks based on his attendance at the Resilient EP project meetings, where he has had the opportunity to meet with researchers and others involved in the project. He has found the information presented interesting, particularly at the higher level in terms of understanding different models and how to relate and scale information from the soil moisture probes to the rest of his farm. • As a result of involvement in the Resilient EP focus paddock, Andrew has gained an improved understanding of soil moisture in absolute terms and the characteristics of the soil releasing it. He said, having the soil moisture probe in the paddock has "reinforced understanding and given us the confidence to install at least one other soil moisture probe on another soil type across our farm."	• In terms of the payoff, he said, "there is no doubt in my mind it has been well worthwhile, and we have got our money's worth back in information, particularly in terms of confidence about nitrogen management." • He explained the investment has enabled more targeted decisions. Using data from the moisture probe has resulted in decisions that have saved on nitrogen applications. • He noted this had recently been a valuable piece of information to present to his bank. Understanding there is moisture available meant he could confidently show his lender that there is currently more soil moisture available than has been there in the past 5 years.

2. Engagement and Communication

Project awareness was communicated broadly through the region through the AIR EP Newsletter, dedicated website and social media as well as an internal project newsletter called the RIG Report to update those most closely involved with what was happening and coming out of the project. RIG meetings provided a very effective opportunity for interaction with researchers and developing mutual understanding around soil water management. Broader messaging in relation to taking action was dependant on the findings from the project trials, with limited data available in the early to mid-stages of the project – momentum in this area increased in the final year. Project outcomes will continue to impact on available information and advice and informing future projects and communication to farmers.

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The AIR EP newsletter was one of the key communication tools used to promote and disseminate information relating to the project. The newsletter is distributed weekly during growing seasons (less frequent at the other times) to 273 recipients (closer to 400 prior to 2022 – a change in newsletter software resulted in a drop in subscribers) and while not every issue included information relating to the Resilient EP project, a number of editions included updates and news related to the project – generally as the lead article.

As a result of feedback provided by RIG members in early 2021, a newsletter was developed specifically to provide critical updates on project progress to RIG members. Eight 'The RIG Report' newsletters were distributed to 42 recipients (RIG members, wider project team, focus site farmers) between October 2020 and April 2022. Topics included: information on upcoming trials; notes from recent discussion group meetings; updates on focus site activities; soil sampling progress; probe audits; and upcoming events. The newsletters appeared to be of high interest, with an average open rate of 75% (i.e. the number of recipients who read the email).

The extension officer role in the Resilient EP project helped raise awareness of the project in the region, extend results, worked with growers and advisors on how they could evaluate and implement practice changes, and facilitated discussion groups so that the key learnings could be worked through in a dynamic group format with peer-to-peer learning. The officer also provided a conduit for bringing project research and development partners together, as well as coordinating and facilitating on-ground activities when needed. The Regional Innovators Group proved highly valuable to this role through providing feedback on the levels of current grower knowledge and potential gaps, as well as how, where, and when to best engage with growers.

Effectiveness of communications at raising awareness and encouraging engagement and use of outputs

There was a general appreciation amongst interviewed stakeholders that the project's communications strategy was reasonably effective in raising awareness of the project.

Most effective for those directly involved – for example, farmers where the validation sites were and farmers in those immediate networks; and consultants involved discussing project learnings with their clients. One project team member described how the project *saw about 300 stakeholders and that has been similar each year by targeting a group in each area.* Dissemination of information

to and engagement with the wider farming community was an issue raised often during the project. It was suggested that one of the issues was the project needing to generate data and results before clear messages could be communicated with confidence – *can't tell people what you don't know*.

Awareness seen to have improved as the project progressed – this was attributed by many to farmer's participation in discussion groups and field days/farm walks. It can be assumed that promotion of these engagement events through the project's communication channels was beneficial and prompted some people to attend. Word of mouth was also seen as a driver, with RIG members and advisers seen as an important part of the communication process.

Branding consistent but competing in a crowded landscape – While the branding was seen by team members as consistent, it was noted the project was operating in crowded landscape and in parallel to other similar industry initiatives, with farmers potentially unaware where certain information had come from or if they were engaged specifically by the Resilient EP project. The issue of attribution was considered to be a common issue with these types of projects.

E-newsletter a valuable communication tool – the AIR EP newsletter were seen by the project team as one of the key communication resources, with the Yield Prophet report updates *always the most clicked on item*. Demonstrating the value of using e-newsletters as an effective channel to distribute project outputs.

Regional Innovators Group

The Regional Innovators Group (RIG) was formed early in the project and consists of twelve influential farmers in the Eyre Peninsula with the goal to *engage researchers and link with the region's farmers to develop techniques to integrate information generated from the probe network, satellite imagery, climate and yield models.*

Meetings were held biannually, with six successfully run over the life of the project. RIG members also occasionally attended project management Zoom meetings and were also invited to attend the project's final workshop held at the end of March 2023. RIG Meeting participants provided feedback at the end of each meeting – a summary of this feedback is included in the table below.

Meetings were an effective method of keeping RIG members updated – Early on the meetings were highly rated in terms helping RIG members understand the project and the role of the RIG, and as the project progressed, they remained highly useful in terms of continuing to update participants on the project.

Feedback from meetings used to improve future meetings – Suggestions provided by RIG members on how meetings or communications with them could be improved were taken on board by project management and resulted in a number of successful improvements, including: the RIG report emails to keep members better informed between meetings; changes to the meeting format to include field trips and reduce the amount of time sitting in a room listening to presentations; and more time for discussion allocated after presentations.

High confidence project will meet objectives – At the March and October 2022 meetings, there was overall high confidence from participants that the project was on track to achieve its panned objectives.

The Regional Innovators Group (RIG) was regarded by all stakeholders interviewed as an essential part of the project, with the success of the project largely attributed to the collaboration between the RIG and researchers.

Regional Innovations Group workshop two at the Yeelanna Focus Field site, September 2020

Overall, the RIG was described as highly active, engaging, and a valuable part of the project and was seen to have provided practical input and direction, helped shape the project, and facilitated interaction between farmers and researchers. RIG member feedback was seen as essential in ensuring research was relevant and useful to farmers in the Eyre Peninsula and allowed for interaction between farmers and researchers at a level that *had never been seen before*, resulting in meaningful outputs with practical applications.


Regional Innovations Group workshop three at the Minnipa Focus Field site, September 2021

RIG members being local farmers themselves was seen as particularly important, as it ensured project outputs remained focused on regionally important issues and relevant to other local farmers. RIG meeting attendees consistently rated the RIG (and the RIG meetings) as being highly effective in supporting the project and providing input into its activities and direction.

Summary of RIG meeting participant feedback

#	RIG Meeting	Participant Feedback Summary
6	**October 2022**	• 15 respondents • Workshop highly useful in terms of updating participants on the project (8.1 avg.). • High confidence the project is on track to achieve its planned objectives (8.0 avg.). • RIG seen to be highly effective in supporting the project and providing input into its activities and direction (8.4 avg.) – *the RIG has given the project direction and kept it meaningful.* • Comments described the great discussion session indoors on the value of the project work and the good wrap up session at the end with everyone having a chance to speak.
5	**March 2022**	• 17 respondents • Workshop highly useful in terms of providing an opportunity to provide input into the project activities and direction (8.5 avg.) – *great discussions and planning for the final year of the project.* • Extra discussion time allocated after sessions highly valued (8.8 avg.) and described as *absolutely key to the success of the meeting.* • High confidence the project will achieve its planned objectives (7.8 avg.)
4	**September 2021**	• 18 responses • Workshop highly useful in terms of providing an opportunity to provide input into the project activities and direction (7.7 avg.) – *a lot of opportunities to interact. Very well facilitated discussions.* • High level of clarity around the role of the RIG and its role going forward (7.4 avg.)
3	**March 2021**	• 20 responses • Workshop fairly useful in terms of providing an opportunity to provide input into the project activities and direction (7.0 avg.) – *a lot of time was spent going round in circles; appreciated the chance I got to better understand the project as well as giving input.* • Workshop felt to have too many presentations and despite some frustrations with the format and loss of direction, participants indicated that positive outcomes were achieved by the end. • Project seen to have a moderate level of value to growers in the Eyre Peninsula (6.1 avg.) – *only likely to be useful for a small number but will maybe get more onboard if they see a benefit. Majority never will go past much more than a passing interest.*
2	**September 2020**	• 17 responses • Workshop highly useful in terms of updating participants on the project (8.2 avg.) – *would have been a 10, but we ran out of time to cover everything.* • Moderate level of clarity on what's happening (6.7 avg.) – *Needed time in the meeting for a summary of the days conclusions/actions/key messages.* • There was some concern whether the expectations of what the data can deliver are realistic and achievable – the complexity of the project was noted.
1	**March 2020**	• 22 responses • Highly useful in terms of understanding the project and the role of the RIG (7.7 avg.) – *great participation by all involved and some great outcomes for moving forward.* • Respondents quite clear on what happens next (7.0 avg.) – *vaguely clear - But I can see a rough guide that will be honed in over time.* • Participants were excited to be a part of the project and were enthusiastic about its goals – *very impressed with the collegiate atmosphere and the strong desire to do good things to improve outcomes; fantastic opportunity that will be great to see delivered.*

Discussion groups

Discussion groups involving RIG members and local farmers were held at the validation sites (focus paddocks), using the core data developed by each of the sites as the basis for discussion. The peer-to peer learning that occurred through the discussion groups helped drive practice change at a local level through a creating a deep understanding of complex decisions.

The discussion groups gave the opportunity for neighbouring growers and their advisors to come together to discuss how the measurement of soil moisture, a good understanding of soil characteristics and environmental conditions can affect their production and risk profile and how they can use that information to become more resilient and more profitable. Each group involved

between 10 to 15 local famers and advisers. The value of peer-to-peer learning when discussing potentially complex decisions was evident through the number of growers returning for each meeting and the size of the groups growing over the lie of the project. The focus paddock hosts were leading, well respected growers in the area which also assisted in the group's dynamics. Group meetings were held twice a year in 2021 and 2022, once in April prior to seeding and the other in June or July. Having groups situated in the paddock in winter gained greater interest and had growers interacting and contributing to discussion.

Through the discussion groups, growers learnt to use soil moisture probes data to help predict yield potential and adjusted inputs accordingly. Four out of the eight focus paddock farmer hosts have begun to use variable rate application of nitrogen. A majority of agronomists in the Regional Innovators Group now use soil moisture probes as an indicator of yield potential when predicting fertiliser input requirements prior to and thought out the growing season.

Stakeholders interviewed made the following observations:

- Validation sites were well chosen, providing a spread of farms across the region and were critical to the project's approach. They were useful in *testing project thinking* and providing measurements and background information on real-world situations.
- Successfully provided a focus for discussion groups, resulting in productive communication and engagement between growers, researchers, and consultants – participants described the sites as inspiring and valuable for knowledge sharing.
- Discussion groups facilitated knowledge sharing and the opportunities for ongoing in-depth discussions provided researchers valuable insights into how growers adapt to new technologies and practices.
- Access to soil moisture data was a key output from the validation sites, with the sites seen to have contributed to improved farmer understanding about soil moisture holding capacity – and as a result improved confidence and decision making particularly around nitrogen application.
- Validation site discussion groups and other activities (field days/farm walks) were described as helping *sync* knowledge and understanding across the region and it was felt the project had contributed to increased interest in using soil probes.
- Some stakeholders were uncertain how much of the project information growers and advisers had taken on board, but the sense was that people were at least asking more questions around the issues.

Discussion group at Cockaleechie, July 2021 (LHS) & Cootra focus paddock site (Oct 2021).

Awareness raising

To create wider grower engagement, listen to grower and advisor feedback that could be incorporated into the project, the extension officer spent time raising awareness of the project through attending and speaking at grower field days, workshops and seminars. Events supported included:

- In 2020, 290 growers were presented to at seven agricultural bureau "sticky beak" day.
- In 2021, 115 growers were presented to across eight pre seeding trial report meetings on the upper Eyre Peninsula.
- In 2021, 410 growers and consultants were presented to at ten agricultural bureau "sticky beak" days.
- In 2022, 100 growers were presented to across eight pre seeding trial report meetings on the upper Eyre Peninsula.

Other extension activities

A range of extension and engagement activities were undertaken during the project including a regional influencers information session in December of the first year of the project, an Innovation Tour in August 2022, N mineralisation virtual workshops in November and August 2022, a Nitrogen Workshop in July 2022, and a final project workshop in March 2023. The six Regional Innovator Group meetings were key extension events held over the course of the project.

Resilient EP Information Session (December 2020): Key influencers in agriculture and regional development on Eyre Peninsula participated in an information session about the Resilient EP project including what are we trying to do, how are we doing it, and what does it mean for our farmers and our region. Feedback included that it was *very helpful in presenting the project on the flow of information, from broad to more specifics, from a range of talkers. It was relatively succinct, and everyone seemed interested. The project will give growers immediate access to information that they have previously gone on by gut feel or intuition.*

EP Innovation Tour (August 2022): The tour involved key farming systems scientists and advisers from across Australia visiting six of the eight validation sites. RIG members also participated in components of the tour including the end of tour workshop in Kimba. The tour was focused around the question: *What are the RD&E gaps/opportunities to increase productivity/ profitability/ sustainability of broadacre rainfed farming systems on EP?* The tour addressed the broader issue of the remoteness of the region and the difficulty in attracting leading scientific minds to the region to review and recommend on future RD&E needs that will grow the prosperity and sustainability of agriculture in the region.

Participants found the discussions between researchers, farmers, and advisers, particularly useful. This type of networking and interaction was a highlight of the tour for many, particularly in terms of *closing the loop between scientific research and real-world needs, raising researcher awareness of farmer issues,* and *drilling down on what determines farming systems decisions.*

Participants in the tour rated the value of the EP Project very highly (average of 8.6/10) in terms of helping farmers make efficient use of soil moisture. The tour itself was rated highly in terms of it identifying the RD&E gaps/opportunities to increase productivity/ profitability/ sustainability of broadacre rainfed farming systems on EP (8.3 avg.). Comments highlighted that the project is *generating great thinking and analysis of water use* and *has clearly stimulated a lot of deep thinking and effort around soils and WUE.* It was suggested though that the project needs to run longer so changes can be implemented and measured/modelled, while challenges associated with engaging late adopters and some problems with the probes and characterisations were noted.

End of Innovation Tour workshop in Kimba, August 2022.

Nitrogen workshop (July 2022): A nitrogen modelling workshop was held in early July 2022 with the aim of being an interactive discussion on current work being done to better understand nitrogen in EP farming systems. Thirty participants attended including advisers, researchers, and farmers. Overall, feedback was very positive, with comments noting it was a great session and very useful to advisers, with one participant praising the event as one of the best conversations that has ever been had about our biggest input nitrogen. Four respondents indicated they would now take actions (change their advice) as a result of attending – e.g. *as an extension officer it gives me a stronger foot to stand on when talking in depth about N mineralisation and the gap between what is measured, then added and the resulting yield*.

Climate Change on the EP (December 2021): Twenty participants attended a workshop discussing the topic *Making sense of climate change projections for upper Eyre Peninsula* which was presented by project team member Peter Hayman. The participatory workshop addressed a range of questions:

- What weather/climate changes have you seen in the last 20 years compared to pre-2000?
- What changes in weather/climate do you anticipate in the next 10 years from now?
- What have been the main changes to farming systems over the past 10 years?
- How do we adapt based on future projections?
- What is needed to make the changes that will ensure that farming on the EP is profitable over the next 20 years?

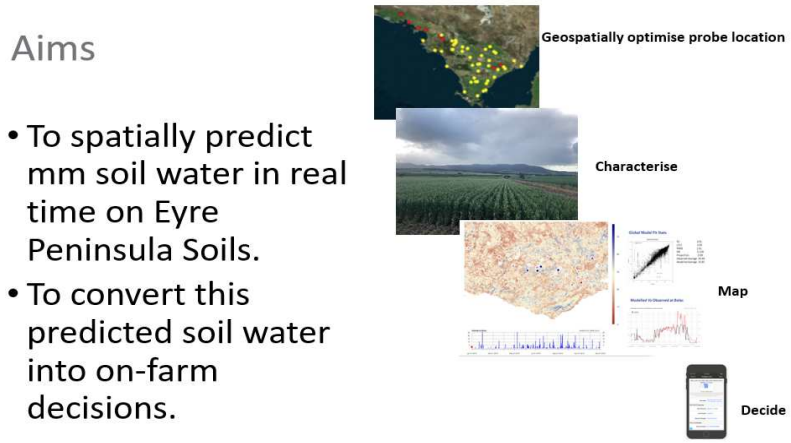
Of those that provided feedback (16), 100% improved their knowledge and understanding of climate projections for the EP as result of the event.

Final Project Workshop (March 2023): At the final project workshop, project partners presented and participated in facilitated discussions on the findings of the project. In the second half of the workshop the project team, RIG members, farmer co-operators and invited guests reflected on the project outcomes in a session led by Jeff Coutts from Coutts J&R. Thirty-four attended including RIG member project research partners, and invited farmer and researcher guests.

Participants at the final project workshop, March 2023.

3. Research and Development

While the intended development of the soil water sensor network did not proceed in the way that was initially envisaged due to sensor limitations and calibration needs, the work undertaken was seen to have been successful in improving understanding and use of probes, as well as the challenges and limitations associated with them. A working product for data visualisation was completed and refined by RIG feedback. The validation sites were assessed as having added significant value to the project in improving the understanding of technology integration in farming practices and the use of soil moisture probes to make informed decisions. The climate risk team was seen to have successfully supported and liaised with others in the project to improve how climate risk and seasonal forecasts are communicated and understood. Three case study farms were selected by the CSIRO research team to test methods for extrapolating point source soil moisture probe data across paddock and farm landscapes, and to develop real time plant available soil moisture maps.



Project flow to achieve aims.

Digital Soil Mapping Approach

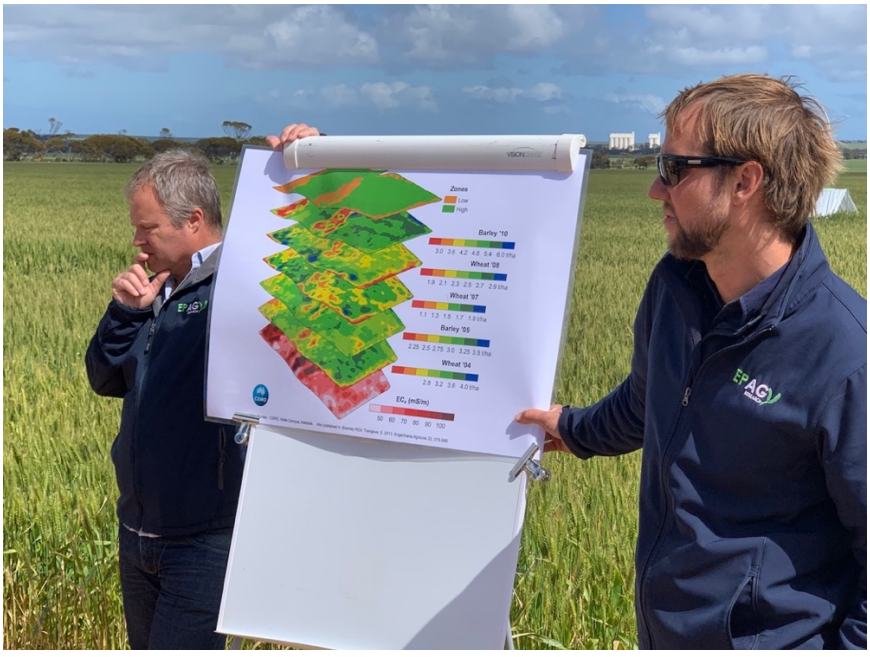
This pilot demonstrated a workflow to extrapolate timeseries soil moisture data from probes on the Cockaleechie and Yeelanna farms to map soil moisture at any time the probe is operating. The pilot demonstrated a statistical clustering method to prioritise soil sampling to cover the farm soils as best as possible. The soil sampling was used to train machine learning digital soil mapping to

estimate available water to 1 m depth across the farm landscapes. The mapping reliabilities were favourable (Cockaleechie: R2 = 0.35, Lin's concordance = 0.55; Yeelanna R2 = 0.42, Lin's concordance = 0.58) although the reliability of mapped extrapolations of soil moisture at certain times validated against concurrent field measurements were variable; the Cockaleechie farm showed a R2 of 0.19 whereas the Yeelanna farm resulted in a R2 of 0.6. The approach seems to show promise as a possible aid to dryland farming decision making in situations where soil moisture probes are available nearby, although more work is needed highlighted by some reliability results. The mapping ground resolution of ~30 m adds to the decision-making utility.

The methodology used in this pilot has applied an analytical workflow to test digital soil mapping (DSM) prediction of plant available water (PAW) and temporal extrapolation from soil moisture probe data, and the results for the Yeelanna farm appear positive. However, further improvements may be possible, for example, assuring that:

- The soil survey design was optimal and that it had covered all the soils.
- The DSM approach was the best possible, including the optimal user set up and algorithm; there several model settings that could have been tested, as well as different algorithms like Random Forests (Wright and Ziegler, 2015).
- Similarly, it is acknowledged that the SLGA (Soil and Landscape Grid of Australia) covariates were likely to have been used beyond optimum given these have been compiled for a smaller scale of application than use here.

One of the key limitations of the approach is the reliance of SLGA data as covariates because of the coarse native spatial resolution of these datasets. Whilst the resolution is inconsistent with precision agriculture (PA) type approaches, the current ability to map PAW across the Yeelanna farm with moderate reliability and the ability to predict PAW at various times from a soil moisture probe is an advancement on current capability.



Discussing data layers at the Yeelanna focus paddock site, September 2020.

Multivariant Regression Approach

The Todd Matthews' farm case study illustrated how information from a soil moisture probe might be extrapolated away from the location of the probe to give information of possible value for decision-making at other locations in the field or farm. Of note was the observation that at times of

likely key agronomic decision making, such as at GS31 – when a mid-season nitrogen (N) fertilizer decision might be made – the range of spatial variation in soil moisture status at any given depth was considerably less than the range of soil moisture status down the soil profile at any given location (this result was obtained at both the Matthews farm and also in another contrasting paddock in the mid-north region; Bramley et al., 2022b). Therefore, the value of a soil moisture probe was probably greater in highlighting differences between seasons, than in being the basis for a targeted management decision at any one time.

Through the analyses conducted in this case study the following conclusions can be made:

- A soil moisture probe can potentially provide useful information; but it is specific to the location at which it is installed.
- An approach based on multivariate regression and using cumulative NDVI, season growing degree days and cumulative net precipitation offers a means of extrapolating soil moisture probe data away from the location of the probe. However, this only works during the growing season since it relies on the NDVI signal from a crop.
- On any given date during the growing season, the spatial variation in soil moisture in both the Matthews 'Focus paddock' and 'Focus Farm' is somewhat less than the variation in soil moisture down the profile. Accordingly, it seems unlikely that a soil moisture probe, coupled with a means of extrapolating away from that probe, will drive a targeted mid-season management decision on an Eyre Peninsula farm similar to that of Todd Matthews.
- Historical yield maps can offer a useful underpinning basis for separating a farm into zones of characteristic performance in the same way that might be done for the identification of paddock-scale zones.
- On the Matthews farm, zoning the farm on the basis of yield did not markedly improve our capacity to interpret soil moisture probe data at other locations on the farm.
- However, at some locations, the soil moisture profile could be seen to be similar to that at the probe; at other locations it was clearly somewhat different.

Where a soil moisture probe is to be used, if some element of probe calibration is to be employed to assist in interpretating probe data at other locations, an extensive soil sampling / moisture analysis program needs to be implemented. As well as covering the range of variation in seasonal soil moisture status (low to high), it also needs to include in-season / in crop sampling. One suggestion might be for a regular monthly soil moisture monitoring program to be implemented, beginning and ending one month either side of the growing season. Desirably, this would be done over a few seasons to ensure that the full likely range of soil moistures are encountered. It would also desirably include measurement of bulk density and determination of CLL and DUL / FC. The latter are discussed in following case study from Jordy Wilksch's farm.

Incorporating knowledge of soil moisture into understanding of paddock variability – A case study from a paddock on Jordy Wilksch's farm at Yeelanna

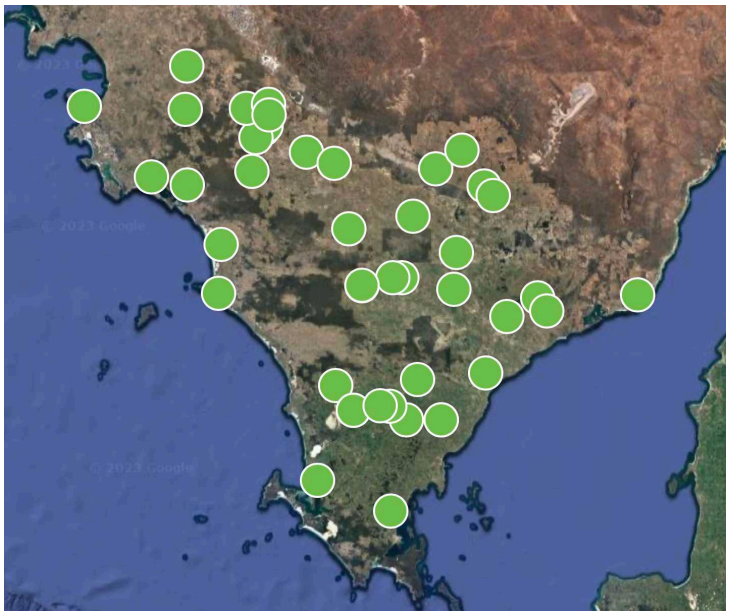
In this focus paddock, because the patterns of variation in yield are stable in time, zones derived from these do a good job of characterising the spatial variation in production potential can be described by the original zone maps. Whereas the effects of sodicity in restricting water uptake were previously assumed to be the main driver of between-zone differences, CSIRO assessments of PAWC and associated soil characterisation infer that the sodicity effect on water dynamics early in the growing season is the more likely major constraint to effective use of PAW by crops grown in this paddock. Accordingly, we would expect that, a basic level of soil characterisation (i.e profile inspection and determination of PAWC) with or without some simple assessment of gravimetric water content, which could easily be done by the farmer would allow the development of rules of thumb for estimating zonal yield potential during the growing season. For example, Jordy Wilksch was to take a soil sample and determine the gravimetric moisture to be around 185 mm of plant

available water assuming that subsoil sodicity was not limiting, this 185 mm could suggest a potential yield of 4.1 t/ha and so guide decision-making accordingly.

We think we can estimate spatial variation in soil moisture using data from a probe and cumulative NDVI, but it seems likely that being able to do this does not add markedly to the farmer's toolkit. This is because the soil moisture variation down the profile appears, in general, to be greater than the spatial variation at any depth, within-paddock. That is, the real value of a soil moisture probe is in what it offers in characterising and comparing seasons. This method however cannot inform a sowing decision. Uncertainty around probe performance is clearly an issue. 'Calibration' of probe values against samples collected in other parts of the field / farm makes sense ('rules of thumb'). However, this requires confidence in the probe data – either in terms of the probe being well calibrated, or its error being constant; understanding of soil variation and/or management zones, so that similar soils can be grouped (i.e., some effort on the part of whoever is doing your mapping); and commitment to collecting good soil moisture data through the season. The merits of doing this depend on how you envisage trying to use the information.

Soil water sensor network development

The Resilient EP project utilized a network of 42 soil moisture probes representative of the major environments and soil types found on Eyre Peninsula. Information collated from the soil moisture probes helped provide growers and advisors real time insights to the levels of stored soil moisture, which coupled with rainfall, form the biggest limiting factor of production in the region. This helped inform more reliable production and yield targets, allowed farmers to match inputs and adjust management strategies to suit.



Eyre Peninsula Soil Moisture Probe Network.

The data generated by the probes was crucial to the project in helping to improve understanding the dynamic relationship that soil type, rainfall and plant water use have across the growing season. Project team members highlighted how research had delivered improved readings and the accuracy of stored water available to plants to within 20-30mm and felt understanding and confidence in soil water management had increased.

RIG members believed the calibration of probes had been highly successful and farmers involved were overall positive about the probes' usefulness. Validation site hosts noted an improved understanding about ground water and interpreting data from the probes over time; and felt the

probes had helped them make decisions about efficient fertiliser use and given growers confidence to make decisions on nitrogen application.

Project team members pointed out the project had improved understanding around the limitations and challenges of using soil moisture probes – it provided valuable learnings about the limitations and capabilities of available technologies and questioned the trust put in some of the technologies. While the research was seen by some involved farmers to still be in the early stages with many unanswered questions, the project had given growers a fair indication of their local area and helped them understand the impact of reduced rainfall on soil moisture.

Inconsistency in soil moisture probe technology in the output they provide has proved to be very challenging and created issues with the implementation of probes as a 'tool' on farm and the use of the data they provide to drive the Square V platform.

Over the course of the project significant learnings were made around the functioning and value of the probes in dryland agriculture. They have the potential to be effective tools that can help provide confidence in decision making at various stages of the cropping cycle, helping farmers to make more informed predictions of yield potential, helping them manage inputs to match. However, it is important the user understands the limitations of this technology. Accurate interpretation of soil moisture probe outputs often requires some level of training, experience, and regular use. Also, probes must be functioning properly to allow their outputs to be used effectively. Understanding what probe outputs to look for when the probe is functioning properly is important.

A review was worked through to locate an arbitrary eight new soil moisture sensors within the existing distribution of 44 as of August 2020. The output showed six new probes could be located in the far west Eyre Peninsula where it is clear visually at least that gaps exist. The remaining two were directed near Cleve on the eastern Eyre Peninsula where a review of evidence suggests soil variability is quite high – so entirely possible that important soils have been missed. It is important to apply this type of quantitative approach to in-fill soil gaps when new probes are planned to increase return on investment by covering a greater range of soil types by probes than currently achieved, and so more farmers can benefit from the spread of probes.

Soil moisture probe at Minnipa.

Soil characterisation

Full soil characterisations were undertaken by SARDI, Minnipa Agricultural Centre, Crop Agronomy group between in 2020, 2021 and 2022 at 34 grower soil moisture probe sites across the Eyre Peninsula. Nine other probe sites have been characterised prior to this project commencing. Soil

characterisation is a critical measurement for estimating plant available water content. The soil characterisations were undertaken following the *'Estimating plant available water capacity', Burk and Dalgleish protocols, 2013*, and '*Field protocols to APSoil characterisations', CSIRO October 2016.*

Soil measurements taken included soil chemistry; bulk density (BD); Drained Upper Limit (DUL– maximum soil water holding capacity - in-field); Crop Lower Limit (CLL – amount water a cereal crop can remove from the soil profile); soil texture and colour; rock content; and photos of soil to depth.


Processing soil samples for soil characterisation by the Minnipa Ag Centre technicians.

2020 sites	2021 Sites	2022 Sites
Rudall, Burton	Cockaleechie, Adams	Baldock, Buckleboo
McEvoy Road, Heddle	Kimba, Baldock	Beinke, Yabmanna (Cleve)
Wharminda, Hunt	Cleve, Bammann	Phillis, Ungarra
Port Kenny, Little	Chandada, Carey	Wilksch, 2 SW Yeelanna
Cootra, Matthews	Minnipa, Heddle 1,	South West
Mt Dutton, Morgan	Minnipa South	Wilksch, 3 Karkoo
Lock, Polkinghorne	Mangalo, James	Pope, Warramboo
Pinkawillinie, Schaefer	Cowell, Kaden	Treloar, Yeltuka
	Solomon (Kimba), Mayfield	Scholz, Minnipa
	Minnipa, Minnipa	Wake, Darke Peak
	Agricultural Centre, N1	Glover, Palkagee (Lock)
	Mt Damper, Michael	
	Goldmine Hill, Glover	
	Lock, Polkinghorne, Good	
	Zone	
	Brimpton Lake, Moroney	

Soil Characterisation Sites – 2020, 2021, 2022

Data visualisation / application development

Post-field trial analysis by CSIRO with the EP Ag Research field trial team, the Regional Innovators Group, and the App team (Square V) evaluated the usefulness of the individual data layers from soil moisture probes at the end of each year to identify the most useful/ adoptable format for delivery of probe data. The resulting user-friendly application provides real time and historical information on plant available soil moisture in mm, as well as calculating a target yield using Yield Prophet Lite®.

The soil moisture app was developed using an iterative process involving the Regional Innovators Group and the project research and development partners. In September 2020 a participatory design session was ran, where participants were split into small groups, and each group discussed

and built their own “ideal user interface” for the proposed app from a selection of components of existing websites and their own sketches. Participants then explained their rationale for their designs to the group, including what was important to them at different times in the season and why. Following the session, sketches and notes were analysed to provide a clearer picture of the information that is important to participants and inform the design.

In November2020, a clickable wireframe prototype of the proposed site for review by the project team and then by the wider team. Feedback was collated and the prototype was updated regularly to incorporate feedback.

Development of the site began in 2021 and was ready for demonstration in early February 2021. External visual design was contracted in line with AIREP brand guidelines, and this has been integrated to the site as part of development. PAW/PAWC calculations were added to the display on the website and temperature correction algorithm to help fix heat-related moisture drift in probes were developed with assistance from the CSIRO team.

The ensuing twenty months involved completing development, error handling, testing and bug fixing. An innovative new section to the site was added in 2022 allowing a user to directly compare the past 4 years of probe data at a specific time of year.

All AIREP soil were added to the site, and the www.probes.airep.com.au site has been live for some time now. A full list of all crop types, soil types and past rotations and this information has been uploaded to the live site.

Soil moisture app output, showing plant available soil moisture down the soil profile.

Data decision field validation sites (focus paddocks)

To build confidence in the decisions that could be improved through an increased understanding of soil water, eight focus paddocks were chosen to more intensively sample, monitor and to test different management strategies depending on seasonal conditions and potential yield predictions. Baseline measurements were taken annually, allowing close analysis and monitoring of the paddocks, with data used in the development of trial work. These paddocks were sampled both close to the soil moisture probe and across the paddock to help provide understanding of how soil moisture and crop production at the probe site related to the rest of the paddock. Criteria for choosing the sites were:

- A functioning soil moisture probe in place for at least 3 years.

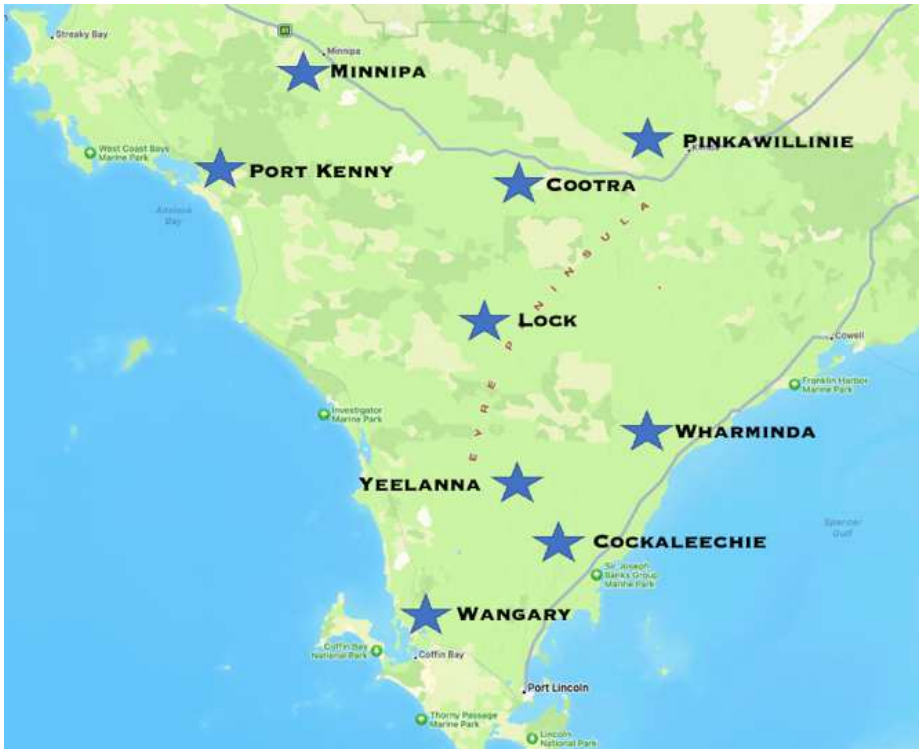
- Regional representative soil types / environments.
- Spread of sites across the region.
- Sites planned to be in cereal in the project period.

Eight validation sites (focus paddocks) were established across the Eyre Peninsula. Within these focus paddocks the team established 24 field experiments (trials and demonstrations) to determine if changing management practices and implementing innovative technologies can improve productivity. It was required that *communication with farmers hosting focus paddocks occurs at least every three weeks, informing them of activities in their paddock and seeking feedback.*

The sites consisted of trials, demonstrations and monitoring points that were used over the course of the project to validate and demonstrate practices that will take advantage of the new ability to make informed decisions on the soil /water interface across the region.

The focus paddocks were also utilised to provide background information for local discussion groups held around each of the focus paddocks. The discussion groups helped increase grower awareness of a range of alternative management strategies, ground truth hypotheses and aided increasing adoption. The focus paddocks were situated at the following sites:

1. Wangary / Mount Dutton – Bruce Morgan
2. Cockaleechie – Dan Adams
3. Yeelanna – Jordan Wilksch
4. Wharminda – Ed Hunt
5. Lock – Kerran Glover
6. Cootra – Todd Matthews
7. Pinkawillinie – Paul Schaefer
8. Minnipa – Bruce Heddle; Port Kenny – Nathan Little



Data decision field validation sites (Focus Paddocks) on Eyre Peninsula.

The sites in provided valuable baseline data used in discussion groups to provide reasons for what is occurring in the paddock; what might happen under various management options; measurements to assist growers to relate small-trial demonstrations to on-farm practice change; and for fine tuning

Yield Prophet which has been used in analysing risk. The overall sentiment from project participants was the validation sites added significant value to the project in improving the understanding of technology integration in farming practices and the use of soil moisture probes to make informed decisions. The CSIRO and RIG team were heavily involved in the development of annual field validation plans.

Trials and Demonstrations

Twenty-four field trials and demonstrations were conducted over the course of the project to test the new ability to make informed decisions on the soil /water interface across the region. The trials were driven by discussions between the Regional Innovators Group and the project research partners. The focus of the trial program included nitrogen decision making, soil amelioration to increase soil bucket size, innovative genetics allowing deeper sowing of wheat, time of sowing to make greater use of soil water, and summer weed control to preserve soil water for the growing season.

Year	Site	Trial
2020	Cootra	Nitrogen Strips
2021	Cootra	Soil Amelioration
2021	Lock	Nitrogen Strips
2021	Minnipa	Nitrogen Strips
2021	Mount Dutton	Soil Amelioration
2021	Wharminda	Soil Amelioration
2020/21	Pinkawillinie	Summer Weed Demonstration
2021	Cockaleechie	Long Coleoptile
2021	Cockaleechie	Nitrogen Rate
2021	Mount Dutton	Nitrogen Rate
2021	Cootra	Long Coleoptile
2022	Cockaleechie	Long Coleoptile
2022	Cockaleechie	N Rate Poor
2022	Cockaleechie	N Rate Good
2022	Cockaleechie	Time of Sowing Good
2022	Cockaleechie	Time of Sowing Poor
2022	Lock	N Rate Poor
2022	Lock	N Rate Good
2022	Lock	Time of Sowing Good
2022	Lock	Time of Sowing Poor
2022	Minnipa	N Rate Poor
2022	Minnipa	N Rate Good
2022	Minnipa	Time of Sowing Good
2022	Minnipa	Time of Sowing Poor

Field trial sites and demonstration sites and topics.

There are several points in the calendar year where management strategies can be refined through an improved understanding of the plant available water status of the soil. These were examined to varying degrees as part of the trial and demonstration program conducted as part of the Resilient Project.

Pre-sowing

Summer Weed Control. Information collected from the Regional Innovators Group (RIG) and discussion groups highlighted a very strong awareness to the value of controlling summer weeds across Eyre Peninsula as a method of conserving moisture for use in the growing season. This was

able to be conveyed visually in several situations where, for a range of reasons, growers with soil moisture probes were slow to control summer weeds and moisture summer rainfall quickly disappeared quickly with the presence of summer weeds.
A demonstration strip run at Pinkawillinie over the 2020/21 summer was able to show that through one application of herbicide, 26mm of plant available water was able to be conserved for the following crop equating to over 0.5t/ha of higher wheat potential.

Crop Choice. For much of the low rainfall zone on Eyre Peninsula, being able to grow crops such as canola profitably requires additional water beyond that falling in the growing season. Conversely in the medium rainfall zone, having a full moisture profile at the start of the growing season can increase the chance of losing crops such lentils to waterlogging. The use of information produced by soil water moisture probes backed up with soil characterisation, both supported by the Resilient EP project, has improved confidence in decisions related to crop choice.
Discussions held as part of post-harvest meetings centred on how the amount of stored soil moisture could affect crop choice for the upcoming year.

Evaluating the benefits of soil amelioration. Ameliorating soils (processes such as deep ripping, spading, delving and clay spreading) have the potential to reduce soil constraints such as soil compaction, and non-wetting soil, and to increase the plant available water holding capacity of the soil and improve water use efficiency.
Monitoring of two trials established as part of another project, located in the focus paddocks at Cootra and Mount Dutton, were continued by the Resilient EP project. In these cases, there was no benefit from a suite of amelioration processes trialled and highlighted gaps in knowledge around understanding the responses to amelioration in different soil types found on Eyre Peninsula.

Sowing

Time of sowing. One of the key drivers of yield improvement over the past decade has been timely establishment of crops to enable flowering in a window that minimises frost and heat risk. This has generally seen earlier sown crops (wheat sown early May) outyielding crops sown in the 2nd half of May.
Work conducted in 2022, a well above rainfall year, growing with above average cloud cover demonstrated that later sown crops don't always yield lower. The 2022 situation could be explained by the lower photo-thermal quotient (PTQ) experienced in that year. Further modelling of PTQ and its impact in the Eyre Peninsula environment needs further investigation to determine the frequency this occurs and the impact it could have on grower practice.

Long Coleoptile Varieties. One of the limitations to early sowing across an environment such as Eyre Peninsula is having to wait for season opening rainfall to create a germination event. The timing of germination events is likely to become more sporadic with a changing climate. One option to help reduce reliance on season opening rainfall is to place seed deeper into stored soil moisture. However, to do this, mechanisms such as longer coleoptile varieties are needed.
The Resilient EP project trialled longer coleoptile wheat genetics and determined these varieties will establish better from seeding deeper than modern shorter coleoptile varieties. For growers to fully adopt these varieties, they will need to yield similarly to current shorter coleoptile varieties and a have access to management system that is able to manage issues such as weed control and phosphorous nutrition requirements.

In crop management

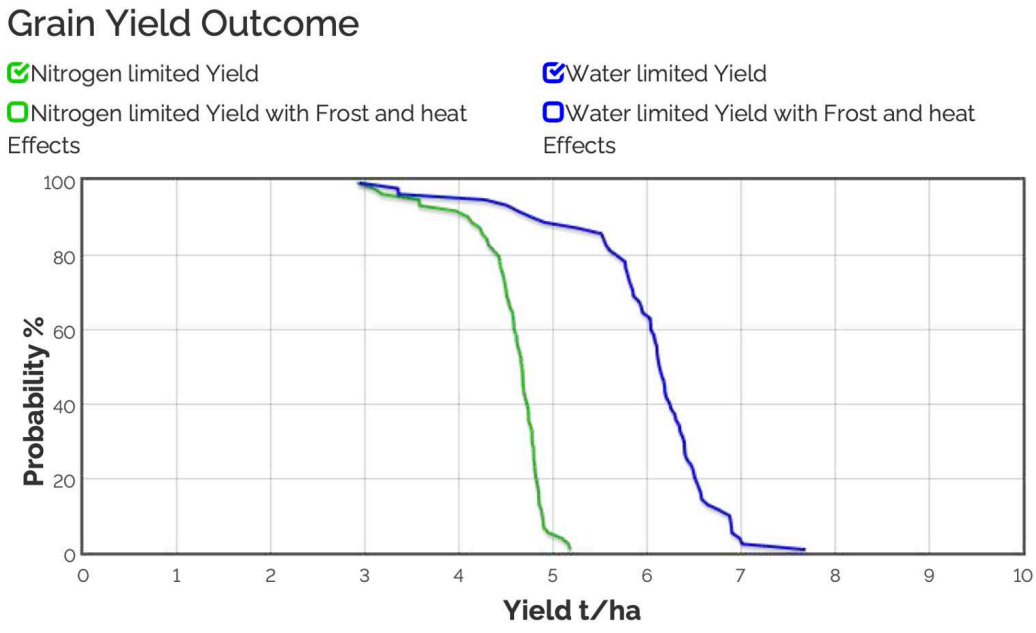
Adjusting Nitrogen rates during the growing season. Much of the trial work conducted as part of the Resilient EP project centred around the application of nitrogen to match seasonal conditions. This work was able to demonstrate that having accurate measurements including start of season soil nitrogen and soil moisture, soil characterisation (how much plant available water a soil can hold) and

some insights into what was driving yield variability across paddocks, helped improve the accuracy and understanding of how to derive a potential yield, it's probability and how to fertilise to achieve it. By having accurate measurements to base calculations helped create confidence in other tools such as Yield Prophet and soil moisture probes and help provided some applicable value in harvest yield maps. Other tools including the use of protein mapping and in season soil nitrogen testing were also shown to help create value in better targeting N inputs.
The quantity of Plant Available Water Capacity (PAWC) of a particular soil gave some insight into the probability of being able to effectively re-act to seasonal conditions with additional N fertiliser. Soils with smaller PAWC (or bucket size) (say around 70mm or lower) wet up and dried down very quickly and were hard to effectively adjust fertiliser strategy in the growing season. These soils benefited from having higher starting soil N values, so little additional fertiliser was required to capitalise on good seasons (it should be noted that yield potential is generally lower on these soils, so don't have the N requirement). Soils with larger PAWC values were able to be more easily managed in season N management and were able to respond to N application in situations when plant available water was high in winter.

Yield Prophet®

The validation sites were modelled for in-season development, yield potential and production risks using APSIM and Yield Prophet®. Feedback from RIG and validation site farmer co-operators helped to fine tune the outputs to reflect conditions more closely on Eyre Peninsula. This was a significant outcome for the project.

Yield Prophet® reports were conducted over each growing season at the eight validation sites in 2020, 2021 and 2022. These reports were loaded onto the Resilient EP project page on the AIR EP web site and communicated through the AIR EP e-news. Yield Prophet® is a software service that uses input of information from the grower/ user to predict yield. Local weather, soil characterisation, nitrogen cycling, crop and variety data all feed into Yield Prophet® (which runs using the cropping systems model APSIM) to produce predicted water and nitrogen limited yields. With new and updated soil characterisations, combined with an understanding of ensuring the varieties selected match the development patterns of crops on EP, the predictions of water and nitrogen limited yield have improved across EP environments.



Example of Yield Prophet® output

What was learnt from the validation sites.

Wangary / Mount Dutton: The quantity and timing of rainfall coupled with the soil type has led to highly variable grain yields on this site. Matching N supply to match demand is extremely difficult to optimise in most seasons in this environment. Discussion groups in the paddock and the Regional Innovators Group meetings have highlighted the importance of a strong balance between a N-fixing break crop and a lesser reliance on the use of synthetic N fertiliser. However, this may not always be the most profitable option.
In 2020 we learnt that N applications applied in small quantities, relatively frequently, through to crop booting gave the best opportunity to obtain the maximum yield in this environment. Trials that took place in this paddock showed us just how valuable high N rates can be in the right season (Paddock N strip trial 2020), but also the in effectiveness of N when used at high rates in a more 'normal' season (N rate trial 2021, Paddock N strip trial 2021). This points toward the need to create a more stable supply of N. This could occur by changing the source of N used or the soil it is applied to.

Cockaleechie: The use of soil moisture probes at this site have been highly valuable in helping determine yield potential and then match N supply to reach potential. This is driven by a high PAWC soil, and the reliable response to N application. The use of variable rate technology is highly beneficial to the grower for liming, seeding rate and nitrogen according to pH, soil type and/or yield potential.
Very high yields are possible in this environment, driven by accurately targeting yield potential and matching N requirement. The use of tools such as measuring soil moisture either through a soil moisture probe or by using accurately calibrated models like Yield Prophet® and measuring soil N have greatly increased confidence in being able to push grain yields to levels past what was once thought only theoretically possible.
The use of grain protein, coupled with yield maps in this environment has the potential to aid in understanding spatial variability of nitrogen levels across the landscape and offers the potential to further refine N application.
Even with relatively high urea prices this site has demonstrated that cropping systems with low legume content can be highly profitable provided N can be applied at rates to match yield potential. (Relatively) high organic carbon appears to be a critical factor in this high production system in helping buffer sub-optimal applications in high production years.

Yeelanna: In 2020 the focus paddock was able to demonstrate the value of stored moisture in a year where spring rainfall was low. In 2019, the northern part of the paddock was terminated and cut for hay to help manage ryegrass. This had the effect of conserving soil moisture (around 60mm), leading to the wheat crop grown in 2020 yielding 2-3t/ha higher than where the 2019 crop was taken through to harvest. This demonstrates the value of understanding the quantity of PAW so that yield can be correctly targeted and fertilised.
Areas of high sodicity and low topsoil pH correlated strongly with lower yielding parts of the focus paddock. The linking of geo-referenced soil tests to yield maps has assisted in identifying the cause of the poorer production. The grower has been aware of this for some time and has applied gypsum and lime as a remedy, however these remain poorer producing parts of the paddock suggesting further intervention may be necessary.

Wharminda: In the Wharminda most growers are acutely aware of the highly variable nature of the crop production (ranging from 1.5t/ha – 4t/ha between seasons). Experience in this area has generally left growers risk averse towards the application of high rates of inputs. As such, robust rotations form the foundation of the N strategy, an example of this is the vetch pasture sown in 2022 amongst wheat and barley (for early ground cover) in the focus paddock. Such a system is a low input system with the potential for high returns in the cropping phase. The use of livestock can add income diversity to the system when cropping is poor, but over grazing can quickly lead to

erosion and needs consideration. Pasture sown deep and early allows feed production as early as possible and maximises ground cover. Robust rotations allow for a minimal input system that has a high yield potential in good years.

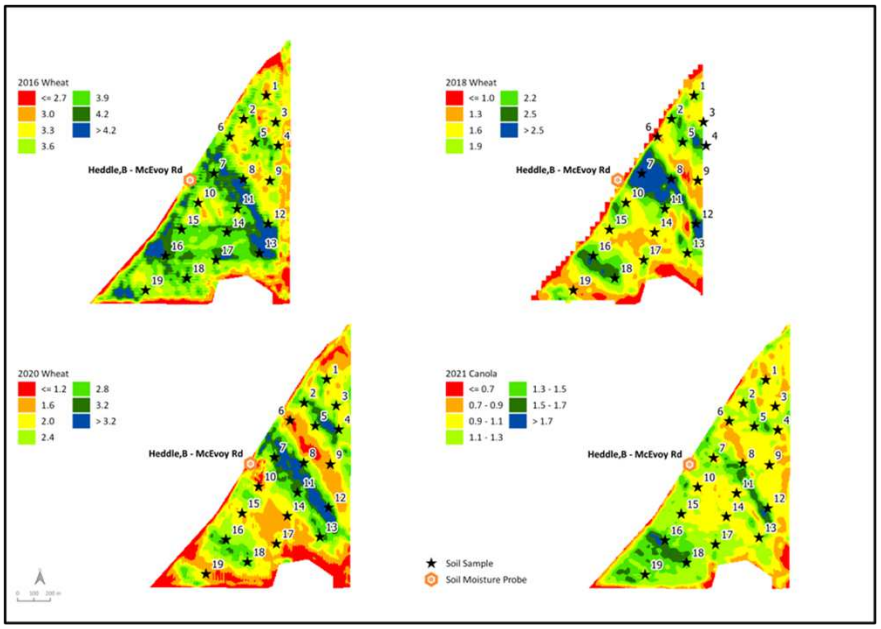
Lock: Canola yields at this site in 2021 were exceptional for the area. The crops establishment was timely, nutrition was good and the selection of a high-yielding hybrid variety all contributed to this. The benchmark for canola prior to this was approximately 1t/ha. Using Yield Prophet® in conjunction with discussion groups a high probability of canola yields greater than 1t/ha was determined. A PAWC of 100% paired with prediction of an average finish saw the forecast of a yield of 2.4 t/ha or higher in 50% of years in late July. August and September were very dry which had a detrimental effect on yield. As can be seen above in the table above, yields still far exceeded the 'normal'. This has now shifted the benchmark for this grower and others in the area for what can be expected of canola. As a result of discussion around this it is also well understood that crop nutrition must match yield expectations. The Regional Innovators Group believes that growers in the area have taken a more assertive yet calculated approach to N applications because of the Resilient EP project.
The scaled-up management practices of this grower does not rely on digital precision agriculture approaches for N management because yield maps and EM38 do not reveal consistent patterns in spatial variation from season to season. Therefore, it is difficult to come to any conclusion as to what spatial management may work best in any particular year until it is too late. For this reason, the grower does not use VRT for N. They do however implement a P replacement program based on the previous year's yields. This is quite common.

Cootra: At this site at Cootra there is a high level of variation in yield across the paddock, with discernible production zones.. These patterns tend to be similar across years which make it make it possible to manage inputs accordingly. By implementing VR technology, the grower has found they can keep inputs optimal to allow high yielding areas to reach their potential and not spend too much on lower yielding zones.
The lack of sub-soil constraints means rooting depth in the Cootra focus paddock is quite deep, with roots found growing to 110cm across large areas of the paddock. This means that PAWC is higher than similar textured soils with high levels of toxic elements. The higher PAWC means that confidence in a base level of yield >2t/ha is increased and input decisions can be matched accordingly. The lack of subsoil constraints could also lend itself to growing alternative break crops. While the grower grows either peas or medic on this farm as a rotation with cereals, other crops such as canola and lentils could be grown quite successfully.
Both heat and frost risk can be very detrimental to crops in this area. The southwest corner of the focus paddock has experienced frost in the past. Heat is an issue in this area. While modern genetics and timely sowing are used to mitigate heat risk, hot days of 30 degrees and greater can occur while crops are filling and can have a negative impact on yield.

Pinkawillinie: Pinkawillinie is one of the northernmost areas of cropping on Eyre Peninsula, not far from Goyder's Line. The spring weather frequently brings cloudless skies which elevates the risk of heat and frost damage to crops. This can make decision-making to chase high yields difficult. In some seasons yield potential may be high with good autumn and winter rainfall, but due to high climatic risk (dry conditions and heat) at the end of the season, applying high inputs to chase high yields can be risky. Many growers implement mixed cropping/ livestock farming systems to help offset risk.
The soil at Pinkawillinie has the potential to store reasonable levels of soil moisture. The use of stored soil moisture from summer months into the following growing season can prove invaluable in years when poor growing season rainfall transpires. 2021 was an example of this. The paddock experienced a decile 2 year with only 130mm GSR. This would generally result in almost no crop however with the 60mm of measured stored water included, the resulting paddock yield was 2.9t/ha of Spartacus barley. This high PAWC means that such knowledge can be a useful indicator of yield potential.
While soil type variation is present at this site, VR application of N is not applied generally. The grower believes that for the size of the variable areas the input of time and cost doesn't provide a

worthwhile return. This is the view of many growers on the upper EP as inputs are generally low to begin with and areas of land farmed are large. The grower does utilise a variable replacement program for phosphorous.
The Pinkawillinie focus paddock is an example of how well the mixed farming system can work on the upper Eyre Peninsula environment. Sheep provide income in poor years to maintain cashflow. Failed crops can be cut for hay to be later fed out in dry spells and annual cropping input costs are moderated as input costs (fertiliser, chemical and fuel) are required over a smaller proportion of land, however the workforce required to run and maintain the infrastructure required to run livestock on the scale that many Upper EP farmers now operate can be extremely difficult to source.

Minnipa: The site at Minnipa has variable PAWC across zones within the paddock. This can be beneficial with the use of VRT to optimise inputs. With the added knowledge of PAW by use of technology such as the soil moisture probe, yields can be optimised in season. The frost risk at this site is lower than other areas of Upper EP, reducing the risk of applying higher inputs. However, hot finishes are frequent, this can be mitigated by correct time of sowing matched with the correct variety of crop.
The grower and others in similar situations on the Upper Eyre Peninsula have a view that higher yielding areas will have a lower water use efficiency in high rainfall years. The exact cause of this is not known. While insufficient N is an obvious cause, there are other limiting factors that could potentially lead to poor WUE in high rainfall years. These include calcareous soils that can decrease P use efficiency. Lack of P and low sowing rates can limit tillers, the number of heads and the number of grains contributing to cereal yields. These are all significant drivers of yield and may limit yield in good areas in high rainfall seasons. These may cumulatively be a cause of low WUE in high rainfall decile years.

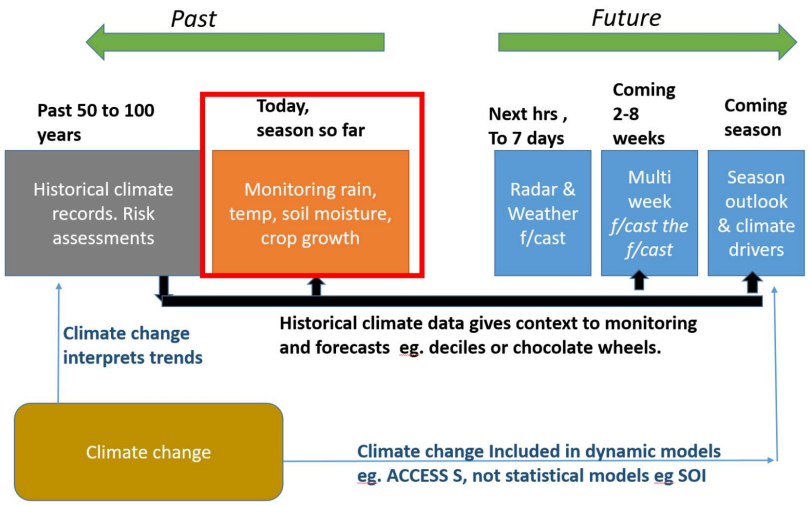


Yield data displaying distinct zones in wheat and canola at Minnipa from 2016-2021.

Climate risk indices and forecast

The SARDI Climate Applications group worked closely with the project research partners and the Regional Innovators Group (RIG) over the course of the project. Peter Hayman attended all six RIG workshops plus the final project workshop. They produced a range of papers that assisted in the discussions on seasonal outlook and climate projections for the region. They also initiated and were involved in workshops and small farmer discussion groups that delved into topics of climate change implications for the region and the practical use of seasonal forecasts when used in conjunction with increased understanding of soil water to make more informed on-farm decisions. The discussions

between the Climate Applications group, the RIG and farmers across the region were always well informed and robust, and provided a key engagement point for the project.



Schematic showing the main information components for climate and forecasting decisions.

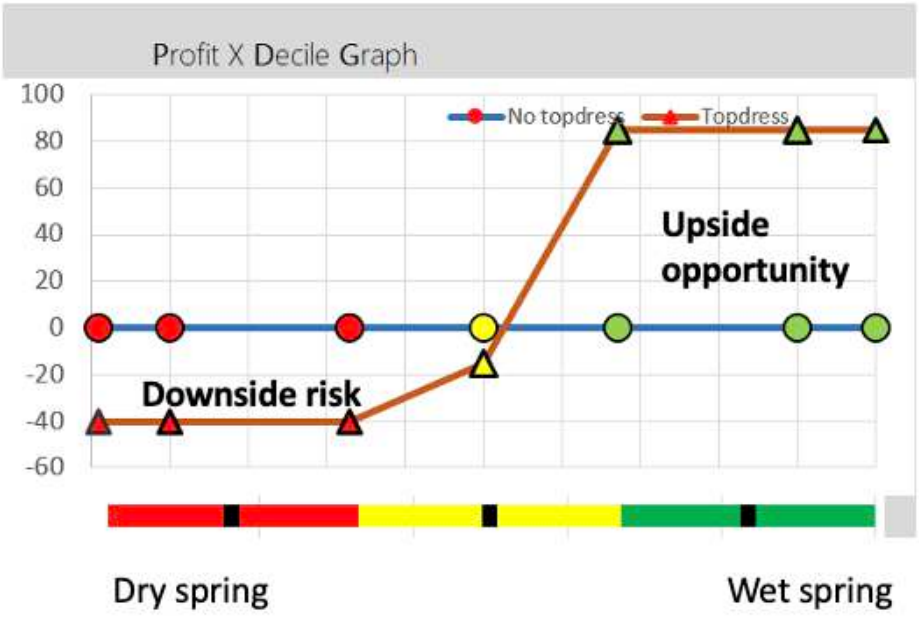
Climate analysis in the early stage of the project was greatly assisted by the project team selecting eight key validation sites, which are representative of cropping subregions of the Eyre Peninsula. This enabled a balance between depth and breadth of analysis. Most growers were aware of how their farm is cooler/warmer and wetter/drier than one of those representative sites.

The topics that were analysed for regional impact and subsequent discussion were:

- Examples of climate analysis that places the coming rainfall and temperature in context of long-term rainfall history and examines the risk of spring frost and heat stress for crops and summer heat stress for sheep.
- Climate analysis for the eight validation sites across the region which providing an explanation of the analysis and a detailed of analysis for each location.
- Developed a set of indices of climate risk for dryland farming on Eyre Peninsula including season break, spring rain, frost, heat stress and heat stress for sheep. A general response from farmers and their advisers was that there was more interest in climate outlooks than monitoring the past.
- Prioritised climate risks and analysed how these risks have changed over recent decades and likely to change in future projections.

The climate risk team successfully supported and liaised with others in the project to improve how climate risk and seasonal forecasts are communicated and understood. The project had helped those engaged understand the variability in climate forecasts and how to use them as a management tool. It was noted in project reporting that *communicating uncertain climate information remains a challenge.*

Working with the CSIRO, the SARDI Climate applications team made use of a budgeting tool developed by Peter Hayman and Barry Mudge to conduct simple sensitivity analysis. Many choices involve some trade-off between the upside and downside risk- a win/loss situation. This is the "crossover" is demonstrated in the profit x decile graph. A win/win situation would see no crossover- assuming we had the numbers right, one choice would always be superior to the other. In the win/loss situation, the wedges in the graphs give us a visual picture of the decision question.



Marginal profit by rainfall deciles tool assessing upside and downside of decisions assisting farmers in making critical in-season decisions.

Over the three-years of the project, annual forecasts were presented to and discussed with RIG members, with this interaction seen as particularly valuable in terms of learning how to improve communication of probabilities. Participants were asked at the March 2022 RIG meeting how the project had improved their understanding of climate risk and season forecasts, with comments overall positive and many noting improved knowledge an understanding – e.g. *better understand context of risks and forecasts for the EP; better understanding the process and complexity of forecasting;* and *now have a fair grasp and improved understanding of climate risk and seasonal forecasts specific to the EP.* Some though were still concerned with the forecasts' reliability – e.g. *reinforces that we still cannot rely on seasonal forecasts to base decisions.* All twenty participants who attended a *Climate Change on the EP* workshop in December improved their knowledge and understanding of climate projections for the EP as result of the event.

			CUMMINS												GSR (Apr-Oct)	GSR	PreSeasonRain	PSR + GSR	PSR + GSI	YIELD	PSR + GSR	2Year	3Year	4Year	5Year
ENSO	IOD	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(mm)	RANK	(mm)	(mm)	RANK	RANK	RANK	RANK	RANK	RANK	RANK
L		1910	5	0	23	6	106	108	186	42	75	64	33	18	586	113	8	595	113	47	113				
E		1911	0	41	5	12	46	103	55	38	48	30	14	51	332	54	11	343	56	93	56	109			
		1912	0	13	83	14	10	63	96	58	87	36	52	15	362	73	42	404	82	110	82	74	109		
E	Ip	1913	0	6	28	11	31	18	34	56	42	57	2	28	249	13	14	263	15	63	15	50	44	98	
E		1914	4	0	42	57	38	14	30	9	13	13	31	35	173	3	14	187	3	5	3	1	7	7	71
	In	1915	5	1	6	45	40	85	85	93	93	24	5	0	463	102	9	472	101	61	101	46	22	41	38
E	Ip	1916	3	1	8	26	50	195	107	70	14	33	50	8	495	109	0	495	108	103	108	110	85	62	78
E	Ip	1917	11	45	28	4	85	82	104	102	89	50	10	9	517	111	22	539	111	53	111	112	111	108	96
		1918	5	3	6	12	54	62	49	93	8	35	1	33	313	45	0	313	40	68	40	101	110	110	101

Historical rainfall data for Cummins on the lower Eyre Peninsula.

Peter Hayman presented at several extension events, including the Minnipa Agricultural Centre Field Day in September 2022 attended by 120 farmers and industry people and at the July 2022 Nitrogen workshop attended by 30 growers, advisers, and industry representatives.

4. Conclusions

Responsive project management and the involvement of the RIG was seen to have been a critical part of the success of the project and the learning that came out if it. Monitoring and Evaluation provided strong support and provided input into reporting and management decisions.
Across the three years of the project, a total of six progress reports were submitted to DAWE – one every six months (February and August). All were *accepted as meeting milestone achievements of the Work Plan.*

The quality and effectiveness of the project management was consistently highly rated over the life of the project, with the monthly meetings a key activity that kept everyone informed of progress and clear on what needed to be achieved going forward. The organisation and running of the RIG meetings were also highly praised by those involved and considered a highly successful part of the project.

This project is very rich in the quantity and types of data being collected and then utilised to make better farmer decisions. For growers and advisors understanding soil moisture, and how that relates to the soil they have can add value and confidence to decisions being made through-out the calendar year.

One of the most consistent 'speed bumps' discovered so far in this extension of this project is the quality of data collected from soil moisture probes and farmer yield maps. Experience in reviewing data and working with farmers improve the way they collect data is improving this

The RIG was seen to have demonstrated its value and a similar approach has a positive role to play in future projects. Broadening extension activities beyond the validation sites was seen as a way of creating greater awareness and interest across the region.

There have been limitations and gaps identified in fully delivering on these longer-term outcomes as summarised below:

Gaps: While the project has helped to improve understanding about plant available water and soil characteristics in the region, there was still some concern about the value of moisture probes Yield Prophet tools, and weather forecasting to support decision-making.

Application: While the probes are acknowledged as providing significant data, the team is still working to understand how to apply that knowledge. There are still gaps in understanding the meaning of specific soil moisture probe readings and appropriate responses. More work is also needed to manage for variability in data across paddocks and larger areas and it was agreed "there is still a long way to go in [achieving the ultimate goal] the project [producing real time sub-paddock scale plant available water (in mm) maps]."

Limitations: There is good evidence to show that the project has had a positive impact on those directly involved, but its benefit beyond this cohort is acknowledged to have been limited to date. Stakeholders generally agreed, project impact on a broader constituency remains to be seen. Relationships have grown through working and sharing knowledge, but messages are yet to connect with wider farmer communities. Inconsistency in soil moisture probe technology in the output they provide has proved to be very challenging. This has created issues with the implementation of probes as a 'tool' on farm and the use of the data they provide to drive the Square V platform.

When asked towards the end of the project what the key issues were going forward, RIG members nominated: Communicating to and engaging a wider audience outside of the RIG including *getting a greater understanding of the value of the project outputs to on farm decision making; Soil water extrapolation; more work on the cumulative NDVI method of assessing plant available water across the landscape;* and *refining the nitrogen mineralisation calculator* were other issues identified. It was suggested the effectiveness of the project should be assessed by how well it is *seen, valued, understood and used by the farming community.*

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Project Funders

Project Proponents

Project Partners