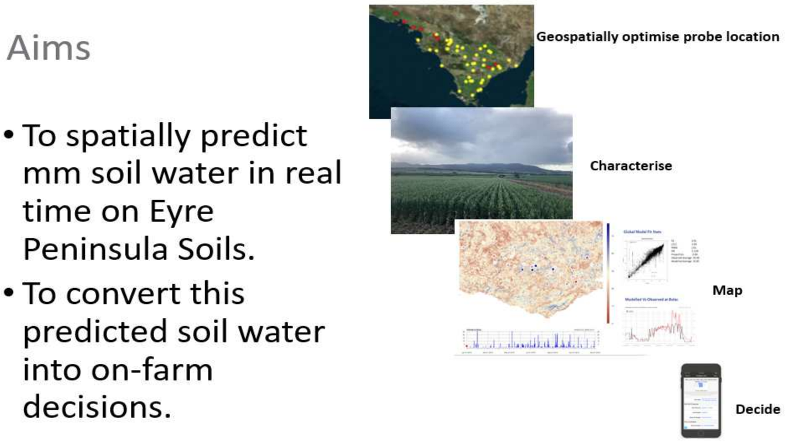
Research and Development

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.

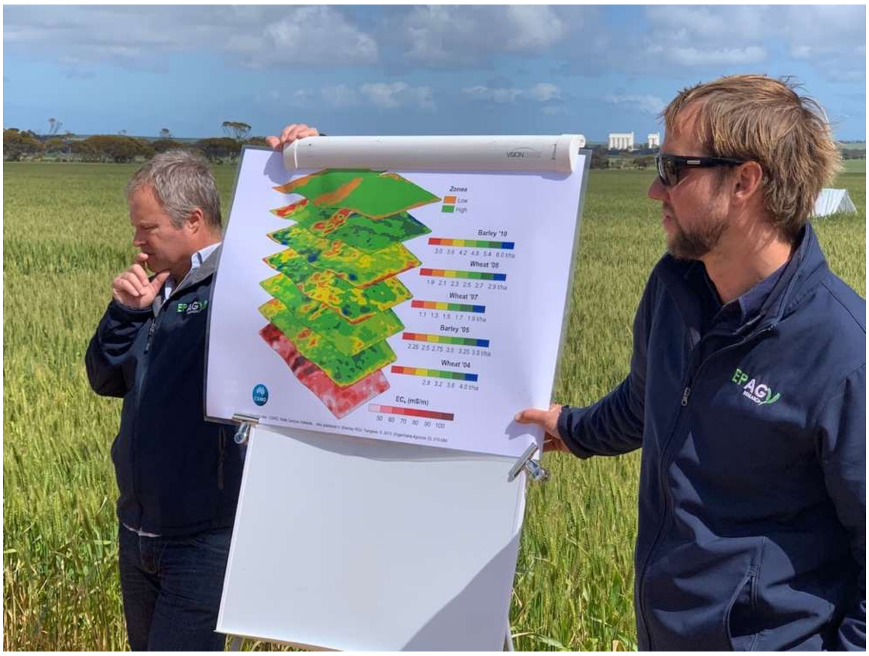
Digital Soil Mapping Approach

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

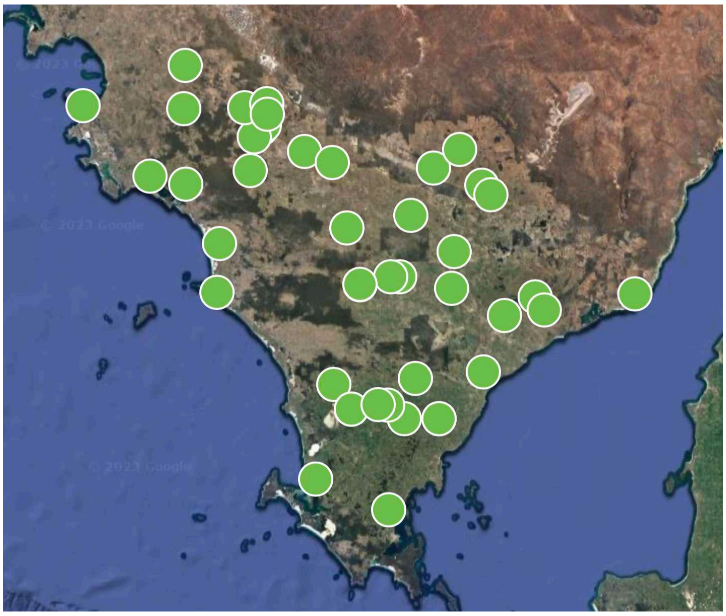
In this focus paddock, because the patterns of variation in yield are stable in time, zones derived from these do a good job of characterising the spatial variation in production potential can be described by the original zone maps. Whereas the effects of sodicity in restricting water uptake were previously 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 McEvoy Road, Heddle Wharminda, Hunt Port Kenny, Little Cootra, Matthews Mt Dutton, Morgan Lock, Polkinghorne Pinkawillinie, Schaefer	Cockaleechie, Adams Kimba, Baldock Cleve, Bammann Chandada, Carey Minnipa, Heddle 1, Minnipa South Mangalo, James Cowell, Kaden Solomon (Kimba), Mayfield Minnipa, Minnipa Agricultural Centre, N1 Mt Damper, Michael Goldmine Hill, Glover Lock, Polkinghorne, Good Zone Brimpton Lake, Moroney	Baldock, Buckleboo Beinke, Yabmanna (Cleve) Phillis, Ungarra Wilksch, 2 SW Yeelanna South West Wilksch, 3 Karkoo Pope, Warramboo Treloar, Yeltuka Scholz, Minnipa Wake, Darke Peak Glover, Palkagee (Lock)

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

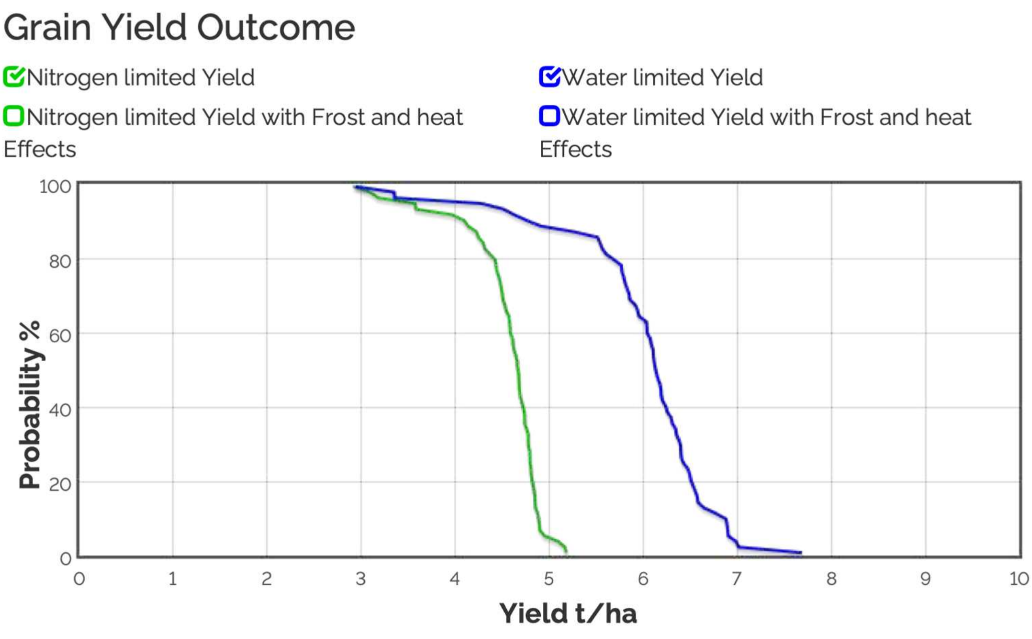
Adjusting Nitrogen rates during the growing season. Much of the trial work conducted as part of the Resilient EP project centred around the application of nitrogen to match seasonal conditions. This work was able to demonstrate that having accurate measurements including start of season soil nitrogen 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.

Trial at the Cockaleechie validation site.

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.

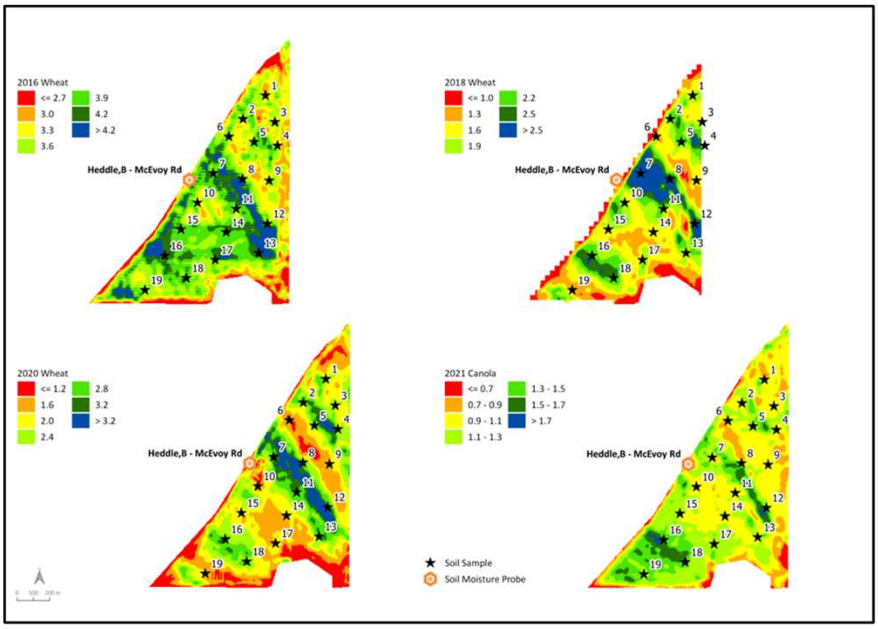
Cootra: At this site at Cootra there is a high level of variation in yield across the paddock, with discernible production zones.. These patterns tend to be similar across years which make it make it possible to manage inputs accordingly. By implementing VR technology, the grower has found they can keep 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.

Cootra validation site.

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

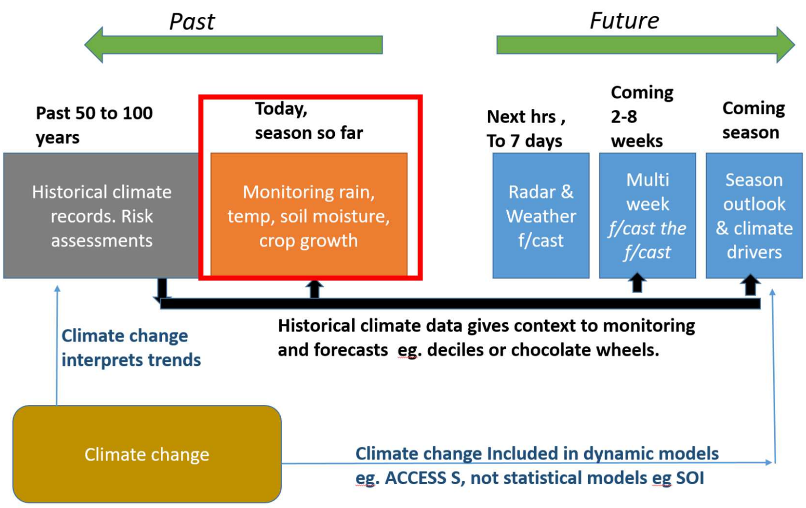
of grains contributing to cereal yields. These are all significant drivers of yield and may limit yield in good areas in high rainfall seasons. These may cumulatively be a cause of low WUE in high rainfall decile years.



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.

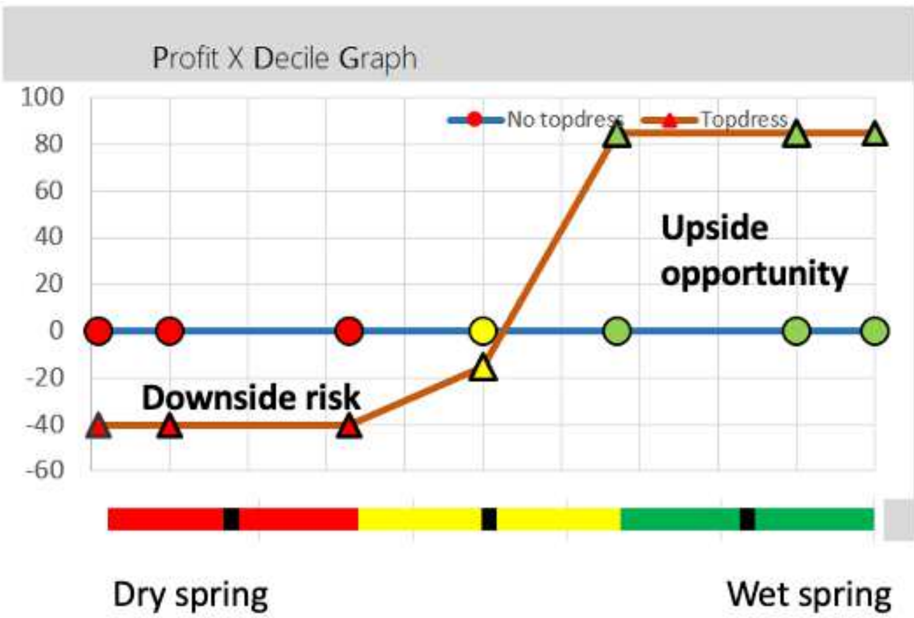
This enabled a balance between depth and breadth of analysis. Most growers were aware of how their farm is cooler/warmer and wetter/drier than one of those representative sites.

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 + GSF	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.

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Project Proponents

AIR EP Ag Innovation & Research Eyre Peninsula

Project Partners

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