WATER STRATEGIES

Review of Existing and Planned Broadacre Irrigation Research, Development and Extension

Smarter Irrigation for Profit Phase 2

23 July 2021

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Summary

Water Strategies was engaged to undertake a desk-top review of the existing and planned broadacre irrigation research, development, and extension (RD&E) for the Smarter Irrigation for Profit Phase 2 project (SIP2). SIP2 is a partnership between the irrigation industries of sugar, cotton, grains, dairy and rice, research organisations and farmer groups. It is supported by funding from the Australian Government Department of Agriculture, Water and the Environment as part of its Rural R&D for Profit program and coordinated by Cotton Research and Development Corporation (CRDC).

The review first identified the key components for the successful adoption of precision irrigation on-farm. Over 50 industry representatives, researchers, farmers, and service providers were then interviewed, and a literature review undertaken, from which individuals of note were identified and followed-up accordingly. Water Strategies also drew from its own experiences and knowledge around the adoption of precision irrigation in New Zealand, which strongly correlate with the Australian experience. The key findings from the review are summarised in figure 1 and explained below:

- ***Monitoring*** – Reliable sensors are available but there is a challenge around their correct selection, installation, and support.
- ***Data Transfer*** – Reliable telemetry systems are available but there is a challenge around their correct selection, installation, and support.
- ***Data Integration*** – Data integration is the biggest challenge including, data ownership and privacy; poor rural connectivity; multiple different approaches to data schema and transfer; cost of developing systems to support data integration; no overarching strategy for data integration at a national level; poor technical understanding at service provider and farm level.
- ***Decision-support*** – There are some decision-support systems now available that combine sensor and weather forecast data to provide future predictions, but most have reliability and accuracy issues unless actively supported by an expert user.
- **System Control** – Reliable proprietary options exist for broad-acre spray irrigation systems and to a lesser extent surface, but there are no proven open architecture options available for broad-acre systems.
- **Farm Support** – Strong farmer extension systems exist, but these need to evolve to better support technology adoption and enable farmer co-innovation.

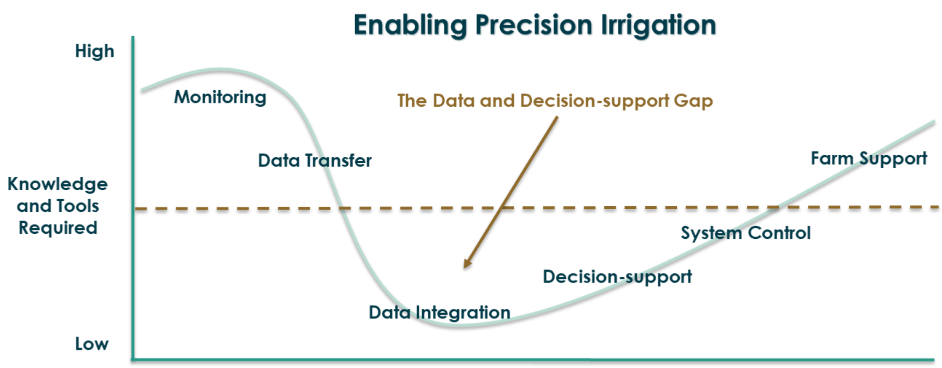

Figure 1: Assessment of the knowledge and tools required for successful precision irrigation.

The SIP2 project is already addressing some of the challenges highlighted above through its existing research and extension work. The following recommendations provide opportunities to further increase the effectiveness of of Australian irrigation RD&E.

Data Integration

1. Undertake precision irrigation data integration case studies.
2. Develop a precision irrigation data integration framework.
3. Develop a farm technology blueprint.

Extension

1. Undertake regular technology scans and engage next generation technology savvy extension specialists.
2. Consider the creation of 'expert knowledge brokers' in the extension system.
3. Provide detailed cost-benefit assessments of precision irrigation technologies.
4. Investigate an innovative, low-risk farm management competition to encourage new efficient and profitable production practices.

Sensors, Decision-making, and System Control

1. Investigate international research collaborations for remote sensing and open architecture system control.
2. Provide sensor installation, maintenance, and technology awareness training for industry extension officers.
3. Develop a service provider capability program that:
    a. Develops and implements training for quality technology installation and data management.
    b. Communicates the need for improved after-sales training and support.

Research Commercialisation

1. Provide pathways for early service provider involvement in research.
2. Implement a 'fast-fail' applied research system.
3. Increase commercial awareness and access to research.
4. Clearly identify and agree upfront how any potential Intellectual Property from research is to be treated.

Background

The Smarter Irrigation for Profit Phase 1 project completed research into areas including irrigation system audits, irrigation scheduling research, investigation of new technology, evaluation of system design and water use efficiency assessments. It demonstrated that improved water productivity hinged on 'getting the basics right' and found that irrigators could achieve a 10 to 20 percent improvement in farm profitability by adopting best practice and precision irrigation technologies.

The future research directions raised in the *Smarter Irrigation for Profit Phase 1* final report included:

- ***Sensors*** - Robustness issues with soil moisture sensors alongside 'set and forget' expectations around sensor life span, have limited the enthusiasm of farmers to recommend their use to others. This has led to the desire to explore if remote sensing technology could be a viable option.
- ***Scheduling*** - Irrigation scheduling is a major challenge. Farmers have indicated they want simple tools, however the complex production systems and multiple factors that go into an irrigation schedule, including forecast, restrict how simple a tool can be. To move from calendar-based scheduling a spatial whole of farm scheduling approach is needed.
- ***Automation*** - Automation of irrigation systems, without making the system too complex to operate and minimising capital investment while ensuring reliability is also a challenge – particularly for surface systems.
- ***Climate Change*** – Increased evaporative losses from storage ponds and soils is a challenge for areas with low water reliability.
- ***Adoption*** – Understanding the challenges and opportunities facing farmers is key to the adoption of any new technology. Including social researchers in research teams to help better understand needs and value upfront, alongside farmer-led 'participative' research was highlighted.
- ***Capability and capacity*** - The uptake of technologies such as Variable Rate Irrigation is currently limited by the capability and capacity to implement, service, and support it across Australia. Other specialist areas such as automation, sensor installation and support also suffer from the same issue.

The *Smarter Irrigation for Profit Phase 2* project purpose was to tackle the challenges identified in Phase 1 by focusing on practical, cost effective strategies to improve the water productivity of Australian cropping and pasture irrigators. The project is a partnership between the major irrigation industries of cotton, dairy, sugar, rice and grains, research organisations and farmer groups. The project is supported by the Australian Government Department of Agriculture - Water and the Environment, as part of its Rural R&D for Profit program, round four.

The objective of Smarter Irrigation for Profit Phase 2 is to improve the profit of over the 4,000 cotton, dairy, rice, grains, and sugar irrigators.

The *Smarter Irrigation for Profit Phase 2* project covers three components:

- Development of new irrigation technologies including new sensors, advanced analytics to improve irrigation scheduling and strategies to reduce water storage evaporation.
- Cost effective, practical automated irrigation systems for cotton, rice, sugar, and dairy.
- A network of 36 farmer led optimised irrigation sites located on commercial farms across Australia.

Under this 14 research and demonstration sub-projects have been funded:

1. Plant-based sensing for cotton irrigation - Dr Hiz Jamali, CSIRO.
2. Evaporation mitigating solution for Australian cotton water storages - Prof. Greg Qiao, University of Melbourne.
3. New tech integrated smart sensing & automation for cotton - Dr Rodrigo Filev Maia, Deakin University.
4. Smart Irrigation control for water and labour savings in rice growing systems - Assoc. Prof John Hornbuckle, Deakin University.
5. Precision automated furrow irrigation for the Australian sugar industry - Dr Malcolm Gillies University of Southern Queensland.
6. Precise real-time automated cotton irrigation for improved water productivity - Dr Joseph Foley and Dr Alison McCarthy, University of Southern Queensland.
7. Scaling irrigation management to support whole farm operations - Andy McAllister, Agriculture Victoria.
8. Gwydir Valley demonstration of the application of the latest digital technologies for precise automated irrigation - Lou Gall, Gwydir Valley Irrigators Association.
9. What is my yield gap? Maximising water productivity - Cath Lescun, Dairy Australia.
10. Beyond Water Smart: Advancing Dairy Irrigation System Performance - Dr James Hills, Tasmanian Institute of Agriculture.
11. Improved irrigation and system selection for increased sugarcane productivity and profitability - Michael Scobie, University of Southern Queensland.
12. Key Learning Sites Southern – Making the most of water - Alex Schultz, DPI NSW.
13. Cross Sectoral Integration and Extension - Lou Gall, Gwydir Valley Irrigators Association.
14. Improving the science of water footprinting - Assoc. Prof Guy Roth, University of Sydney.

Water Strategies has looked at each of the above projects, except for evaporative losses from storages and water foot-printing, as part of its desk-top review and provided general recommendations for the overall improvement of broadacre irrigation RD&E in Australia.

RD&E Review Findings

A systems diagram for the successful implementation of precision irrigation is shown in figure 2. Each component of the system needs to be in place and well-supported for the successful adoption of precision irrigation on-farm.

The Water Strategies RD&E desk-top review has been undertaken based on this systems diagram.

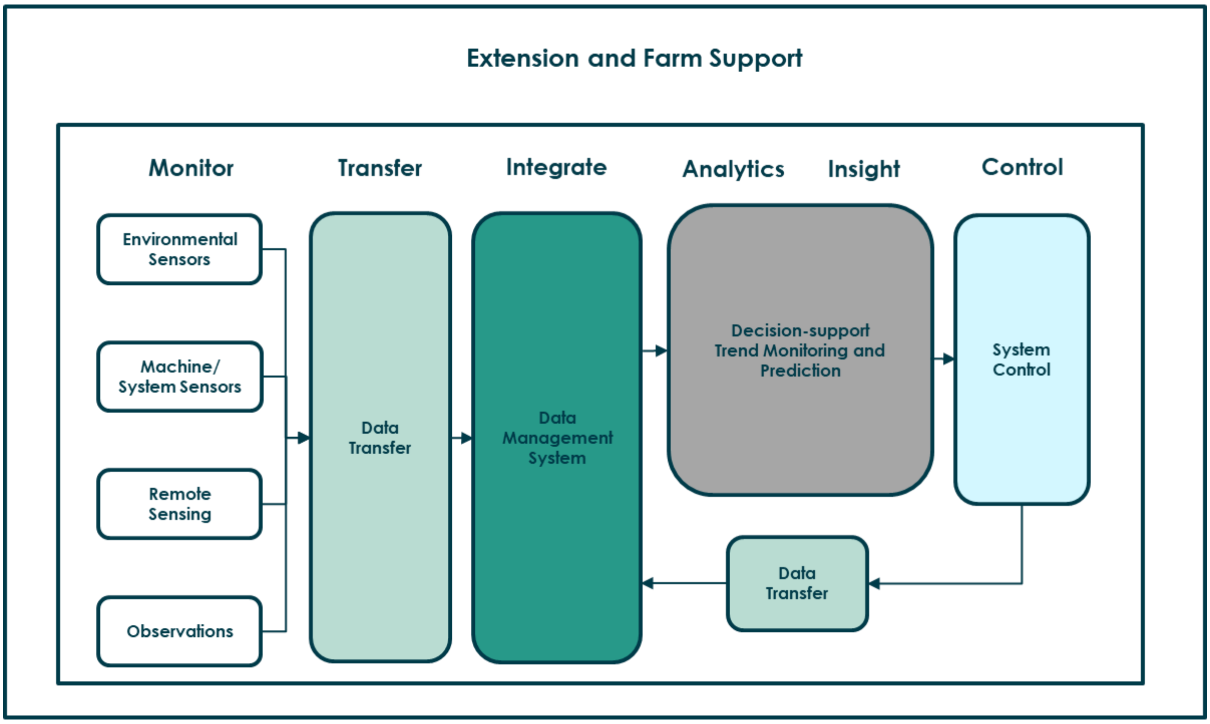

Figure 2: Systems diagram for the successful adoption of precision irrigation

A summary table of the current state and future RD&E needs for each component of the system (in relation to the SIP2 research projects and more generally) is provided in table 1. Extension and farm support aspects have been integrated into the monitor, transfer, integrate, analytics and insights and control sections within the table.

An explanation of the key challenges and resulting recommendations follows table 1. The recommendations included consideration of:

- Strategic system interventions,
- Future investment,
- Potential collaborations and partnerships, and
- Enhanced engagement.

Table 1: Summary table of the current state and future needs for precision irrigation

Element		Current State	Future Needs
Monitor	**Environmental Sensors**	• Proven sensors available. • Strong commercial research and development programmes in place. • Sales driven sensor selection process. • Installation quality control issues. • Limited post-installation support.	Research and Development: • Intelligent sensors (self-diagnostics and self-learning). Farmer Extension: • Sensor selection. • Data interpretation. Service Provider Extension: • Quality management systems. • Installation training. • Trouble shooting. • Challenging the current business model.
	Machine/ System Sensors	• Proven sensors available. • Strong commercial research and development programmes in place. • Installation quality issues. • Some post-installation support.	Farmer Extension: • Sensor selection. • Data interpretation. Service Provider Extension: • Quality management systems. • Installation training. • Trouble shooting. • Challenging the current business model.
	Remote Sensing	• Commercial thermal and NDVI remote sensing services recently available but	Research and Development:

		can be subject to reliability and accuracy issues. • Much research into the use of thermal and NDVI remote sensing for irrigation decision-making is occurring including through SIP2, in the commercial sector and internationally.	• Stock-take of recent and current thermal and NDVI research to identify opportunities for collaborations. • Continued research into thermal and NDVI remote sensing for informing irrigation decision-making. Focus on deriving the crop coefficient and relating to in-situ sensor data. • Understanding options for the commercial delivery of remote sensing: o Satellite. o Light Aeroplane. o Unmanned Aerial Vehicle. Farmer Extension: • Current risks and future opportunities around remote sensing techniques for irrigation.
Transfer	**Data Transfer**	• Proven telemetry systems available for radio and cellular. • LoRa based products often have reliability issues. • Battery life issues. • Strong commercial telemetry research and development programmes in place. • Limited in-situ product testing. • Installation quality control issues. • Level of service needs not well understood by both farmers and service providers.	Research and Development: • LoRa reliability. • Compact battery technology with solar. • In-situ product trials for Australian conditions. Farmer Extension: • Telemetry system type, application, and life span. • Level of service requirements. Service Provider Extension: • Quality management systems. • Installation training. • Level of service requirements.

Integrate	**Data Management Systems**	• Diverse range of data management systems - centralised to distributed, and proprietary to open architecture. • Limited farmer understanding of different data management systems. • No Australian Agritech strategy to address the data integration challenge.	Research and Development: • Use case study for agricultural water use to identify data integration issues and solutions. • Develop a data interoperability framework for agricultural water use. Farmer Extension: • Farm data strategy and due diligence around service providers.
Analytics & Insight	**Trend Monitoring & Prediction**	• Limited understanding of the level of decision-making required for 'efficient water use' in the different irrigation and production systems. • Multiple disparate systems make data analytics and insight difficult, particularly where proprietary systems involved. • Some proprietary solutions exist, but all have limitations. • A few open architecture solutions exist but data interoperability is challenging (particularly with proprietary systems). • No open architecture end-to end solution exists that integrates external farm water supply with farm distribution, control, and decision-making.	Research and Development: • Understanding the level of decision-making required for 'efficient water use' in the different irrigation and production systems. • Improved data interoperability and encouragement of open architecture solutions. • Integration of farm water supply data with farm scale distribution, application, and decision-making. Farmer Extension: • Communication of return on investment and wider cost-benefit of improved decision-making. • Technology specialists with production system knowledge to assist farmers finding the right solution. • Farm data strategy • Due diligence around service providers.

Control	**System Control**	• Spray irrigation control solutions well developed - mainly proprietary but some open architecture solutions. • Surface • irrigation control solutions less well developed - a proprietary system exists but only bespoke options available for open architecture. • No end-to-end solution exists that integrates external farm water supply with farm distribution, control, and decision-making. • Understanding of system control redundancy needs.	Research and Development: • Further exploration of the open architecture approach for surface irrigation, noting solutions that are already well-developed for industrial solutions. • Integration of control systems for water supply to farm gate and water distribution and application behind the farm gate. • Understanding critical system redundancy needs. Farmer Extension: • Communication of return on investment and the wider benefits of improved control. • Technology specialists with production system knowledge to assist farmers finding the right solution. Service Provider Extension: • Training programmes.

Data Integration

Data integration is perhaps the biggest challenge for the widespread adoption of precision irrigation (and precision farming more generally) in Australia. Challenges include[1]:

- Some data is still recorded in paper-based systems.
- Data ownership is often unclear and not defined in service provider agreements.
- Farmers and their peak body representatives hold concerns around data privacy, which often leads to an overly precautionary approach to data integration.
- Service provider technical capability is improving, but there are still significant knowledge gaps.
- Only a small minority of farmers have developed a cohesive technology strategy for their farm.
- Internet access is variable, especially in rural areas.
- There is limited data sharing, and as a result a proliferation of multiple, often overlapping systems.
- Data integration is often hindered by commercial interests that perceive the data rather than the insights it creates as the point of sales.
- The significant cost of developing systems to support data integration and building the business case for future investment in this.

During the review almost every interviewee commented or alluded to one or more of the challenges above.

Post the interviews inquiries were made into recent and current initiatives for improving data integration in the Australian Agritech sector. From this there appears to be no initiatives currently under way beyond the Australian Farm Data Code released in February 2020[2]. This outlined seven voluntary farm data principles for those that collect, use, or share data relating to farmers and their businesses, but has had limited uptake.

Recommendations

1. **Undertake precision irrigation data integration case studies.**
2. **Develop a precision irrigation data integration framework.**
3. **Develop a farm technology blueprint.**

Finding solutions to the data integration challenge is critical for the future adoption of precision irrigation. A practical way forward would be to work with the Agritech sector to undertake case studies that identify the specific data integration challenges for precision irrigation and use these to inform and develop a future data integration

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[1] Alongside the interviews challenges have been informed by 'The Future of Agricultural Technologies' 2020 report by ACOLA (Australian Council of Learned Academics) alongside recent work in New Zealand as part of the Agritech Industry Transformation Plan.

[2] Farm Data Code, Edition 1 2020, National Farmers Federation.

framework. This framework should clearly identify potential incentives alongside where a more regulated system, e.g., standards, could be advantageous.

The approach would include:

- Understanding the current data integration landscape for precision irrigation (both surface and spray) including its challenges and opportunities.
- Understanding the different data interoperability components and the cross-cutting concerns relating to these, for example, identity and control; data specifications; technical enablers; data governance.
- Identifying and addressing common issues and potential incentives from the case studies, noting there will be generic issues raised relating to digital and farm identity, and data governance.
- Consolidating all the above as a basic data integration framework.
- Communicating the findings to increase understanding and support by farmers and service providers and encourage uptake.

This Precision Irrigation Data Integration Framework project could be linked or amalgamated into any future Australian initiative around farm data integration. It may also create a catalyst for more urgent action noting most interviewees recognised this was needed.

In undertaking this work there is potential for collaboration with:

- *Australia New Zealand Agritech Council.*
- *Australian Agritech Association.*
- *NZ Agritech Industry Transformation Plan - Data Interoperability Initiative*[3]*.*
- *AgGateway*[4]
- *NZ Farm Data Standards*[5]

While farmers are generally becoming more technology savvy (many having learnt from past mistakes as highlighted by the farmer interviewees), providing a blueprint for them to think strategically about technology investment would be extremely beneficial, particularly for those yet to embark on the technology journey. The blueprint would include explanations of:

- Terminology,
- Principles,
- Data Systems, and
- Key decision-making considerations.

The extension method for the blueprint would need careful consideration due to the rapid pace of technology change.

[3] https://www.mbie.govt.nz/dmsdocument/11572-growing-innovative-industries-in-new-zealand-agritech-industry-transformation-plan-july-2020-pdf
[4] https://www.aggateway.org/
[5] https://www.datalinker.org/

Extension

Farmer (and service provider) extension and support is the other critical component for widespread adoption of precision irrigation. The SIP2 projects have a strong focus on extension, however there is scope for improvements.

The current sector extension models range widely. This is understandable as each sector has a unique set of characteristics and circumstances. Some sectors have established extension entities with comprehensive extension strategies for connecting both growers and farm consultants with research outcomes, including clearly defined measures and targets. Others run more traditional project-based extension initiatives alongside a repository of information. A high-level overview of each sector is provided below.

Sector	Extension Entity	Approach
Cotton	Cotton Info Unincorporated venture between Cotton Seed Distributors, Cotton Research and Development Corporation and Cotton Australia	Centralised dedicated extension entity run by a joint management committee, with a detailed strategy. Programme delivered through Regional Extension Officers, Technical Leads and *my*BMP support staff, each with clearly defined roles.
Rice	Rice Extension Rice Growers Association and AgriFutures	Centralised small extension team run through the Rice Growers Association. Programme delivered through three regionally based extension officers that collaborate with SunRice Extension Officers.
Dairy	Regional Development Programs Dairy Australia	Decentralised industry-based service and extension network where eight independent incorporated bodies are responsible for the Dairy Australia communication and extension activities, each with their own prioritised strategy. Individual regional extension programmes delivered through regional extension officers and project officers.

Sugar	Multiple – Sugar Research Australia, Productivity Services, Private Providers and Canegrowers	Decentralised system. Sugar Research Australia translate the research and train the trainers. Productivity Services, Canegrowers and private providers undertake extension.
Grain	Grains Research & Development Corporation	Extension activities supported directly through GRDC. Dedicated extension staff in regional offices with a focus on working with key farm influencers primarily including grower groups but also with farm advisors.

Australia is well-renowned for its farmer extension programmes and support initiatives such as the proposed Queensland Extension Model of Practice[6] that help to better equip those that undertake farmer extension. A similar initiative has recently been implemented in New Zealand through the Red Meat Profit Partnership Action Network Lead Facilitator training[7].

Successful farmer (or service provider) extension must be farmer-centric, working with farmers to support them identify their challenges and opportunities and help them discover and implement solutions to these. Adopting a co-innovation approach is also essential for effective practice change as it goes to the heart of the 'farms culture' helping to change long-held beliefs and values. Trusted relationships are key to any extension programme as is evaluating its success based on approaches such as Bennetts Hierarchy, or more specifically assessing participants KASA change (Knowledge, Attitudes, Skills and Aspirations) noting practice change is often only observed over the longer-term.

The review noted some significant challenges ahead for extension providers. These include:

- Extension advisors are typically generalists or agronomy specialists, and therefore unable to provide the technology support required to help farmers feel confident in adopting precision irrigation.
- There is poor farmer understanding of the return on investment and wider benefits for the adoption of precision irrigation.

[6] Queensland Extension Model of Practice, 2020
[7] https://www.rmpp.co.nz/page/our-research/

- There is poor farmer understanding of the ‘right precision irrigation solutions’ for their farm and how to go about determining this.
- Some sectors engage closely with their sectors service providers and see them as a key pathway for communicating their research outcomes, for others this relationship is not as strong.

Recommendations

1. **Undertake regular technology scans and engage next generation technology savvy extension specialists.**
2. **Consider the creation of ‘expert knowledge brokers’ in the extension system.**
3. **Provide detailed cost-benefit assessments of precision irrigation technologies.**
4. **Investigate an innovative, low-risk farm management competition to encourage new efficient and profitable production practices.**

Sensors, telemetry, data management and system control are the new face of farming. Farmers urgently need extension advisors who ‘understand technology basics’ and that can help them take a strategic approach to future technology adoption. To be clear this is about extension providers having a good enough understanding of the technology to assist farmers with their decision-making. Individual service providers are responsible for providing technology support for their product. At first it is likely consultants or arrangements with commercial providers will fill this gap. However, over the medium-term specialist technology focused extension roles need to be created if sector extension programs are to remain relevant.

Expert knowledge brokering involves a range of practices; the identification and localisation of knowledge; the redistribution and dissemination of knowledge; the rescaling and transformation of knowledge. Expert knowledge brokering is far more than simply transferring knowledge from one person to another – it involves the two-way transformation of it.

While many of the sectors extension entities and activities are extremely advanced in nature, the ‘expert’ knowledge broker recommendation is based on an observation from the interviews. Within the system there appears to be many ‘generalist’ knowledge brokers facilitating the transfer of knowledge, but limited numbers of ‘expert’ knowledge brokers helping to transform it. Knowledge transformation includes:

- Working with farmers and service providers to identify their challenges.
- Guiding the researchers with their research design and providing practical feedback as their research progresses (supporting the fast-fail system).
- Translating the end research for practical application.

AgriLink is another project of note that is currently being undertaken by all the EU member states. Its goal is to stimulate transitions towards more sustainable European agriculture by furthering the understanding of the roles played by a wide range of advisory organisations in farmer decision-making and enhancing their contribution to learning and innovation. A conceptual framework has been produced that provides valuable reading for anyone designing, delivering of reviewing agricultural extension programmes[8].

Many interviewees mentioned the need for applied research with more rigorous cost-benefit analysis. This would build on the traditional 'case study with a list of system specifications and costs' approach that was observed[9]. A rigorous cost-benefit analysis would more clearly demonstrate farm profitability gains using measures such as EBIT (Earnings Before Interest & Tax) and EVA (Economic Value Added) alongside consideration of environmental and social benefits. It is important a measure such as EVA is used as it accounts for the cost of capital (the value a business generates from an investment).

Specific areas for applied research included:

- An analysis of the cost-benefit of the different precision irrigation technologies (sensors, partial or full automation and autonomous) for the different irrigation system types (range of surface and spray systems) and production systems in relation to improved profitability and water (and nutrient) use efficiency. Case study farms where some of this data has been gathered already could be used for this to reduce costs. Regional factors should also be considered, for example, the cost-benefit for water-level automation in rice would increase as you moved into colder growing areas.

  Key aspects to focus on in a cost-benefit analysis include cost of capital; labour savings; increased crop yield; decreased water use (water, pumping and maintenance cost); decreased drainage (fertiliser cost); social benefits (well-being); environmental benefits (intergenerational farm management and pre-empting potential regulation).

- Practical comparisons/ demonstrations of the different sensor installation requirements and their interfaces (set-up and interpretation). Noting that for most mid-range price sensors quality installation not the sensor itself is the challenge.
- Practical comparisons/ demonstrations of the different telemetry installation and operation requirements alongside their data hosting options, including the data integration platforms. The data hosting and integration options should be linked to the technology blueprint project.

Through the review process a particularly innovative approach to farm extension was observed through the University of Nebraska's Research and Extension Centre's,

[8] https://www.agrilink2020.eu/our-work/conceptual-framework/
[9] https://www.cottoninfo.com.au/sites/default/files/documents/Irrigation%20Guide_2019%20NEW%20Exec%20PRINT.PDF

Testing Ag Performance Solutions (TAPS) programme[10]. This initiative is based on the traditional yield contest concept but has also built-in profitability and environmental (water and nutrient use efficiency) components. It has potential for application in Australia through producer and farming systems groups.

For the competition participants come together as a team (usually representing their town or district) and each team is responsible for the farm management decisions (including water and nutrient) on three randomised plots within a paddock at the research centre. The research centre field-staff then undertake these actions on the plots. Partnerships with technology providers and researchers allow the opportunity for participants to try new and emerging technologies to aid their decision-making in a low-risk environment.

The competitive approach to extension, peer to peer learning, and ability to trial new approaches has sparked huge interest by farmers in Nebraska, and as a result the competition has now gone interstate.

[10] https://taps.unl.edu/

Sensors, Decision-making, and System Control

Sensors are a critical part of precision irrigation. Most farmer interviewees commented on poor sensor reliability alongside the poor level of service from service providers. This lack of confidence in the basic application of sensors is an immediate barrier to progressing further with precision irrigation.

Further issues raised during the interviews were:

- Poor in-situ sensor installation and maintenance.
- Farmers commented that service providers are sales not solutions focused, resulting in some farmers selecting products that are not fit for purpose, and as a result now being wary of future investment.
- Farmers also commented on the need for better after sales training and support. This is resulting in poor technology performance and technology rejection.
- The service industry commented that their main challenge was around the price point - 'the race to the bottom'. Farmers did not recognise the benefits and increased value that sensors and automation created.

The SIP2 has a strong research focus around sensors, decision-making, and control however, greater collaboration with overseas researchers and commercial providers could improve future RD&E activities achieved.

Recommendations

1. **Investigate international research collaborations for remote sensing and open architecture system control.**
2. **Provide sensor installation, maintenance, and technology awareness training for industry extension officers.**
3. **Develop a service provider capability program that:**
    a. **Develops and implements training for quality technology installation and data management.**
    b. **Communicates the need for improved after-sales training and support.**

A common issue raised by interviewees was sensor reliability. This has significant implications when sensors are used for automation. Sensor quality and reliability is strongly linked to price however, some are better suited for certain applications than others. There is no easy way of relaying sensor performance information without robust and credible information to back up any claims made. This may take a couple of growing seasons by which time new sensors will be on the market and the trials would have to be repeated.

An alternative approach is to step farmers through the automation process, helping them identify where the critical points are in their system and discussing the need to select technology based on function and performance rather than price. System redundancy is also part of this discussion.

Intelligent sensors that can self-diagnose and self-learn are the ultimate answer to this issue. Self-diagnostic sensors are commonly used in industrial automation processes and the price point is starting to come down to levels where they can be applied in other industries. Washington State University has a research project involving self-learning soil moisture sensors, which use soil water dynamics to calculate soil water holding capacity. They are working on algorithms to pick out 'bad data' and the sensor then notifies the service provider when the sensor is not reading correctly.

Another example of machine learning sensors is Lindsay's recently announced, 'Smart Pivot'[11]. The aim is to use predictive analysis to identify issues before they occur by monitoring at the component level. This is based on the industrial automation process.

A common point raised from both farmers and extension officers during the interviews was that the cost-benefit of installing sensors and automation was unclear. While there have been many projects demonstrating how technology works and field days demonstrating different sensors to farmers, there are no projects that have established the actual cost-benefit of installing sensors and automation. A detailed explanation of this has been provided in the Extension section.

Remote sensing techniques provide much potential for more accurate irrigation scheduling. The approach uses satellite, light aircraft or unmanned aerial vehicles to gather whole of farm sensor data (hyperspectral, multispectral, thermal and/ or LiDAR) from which a spatial crop coefficient is derived. These are then applied to a spatial water balance model (management zones), and in combination with weather forecasts provides predictions of future irrigation demand.

Despite the potential of remote sensing techniques, there are challenges with its reliability and accuracy over the growing season. Some of the challenge relates to the availability and cost of imagery at the required resolution and frequency. The other part of the challenge is which indices to use (which produce the most reliable data for a given situation). The current commercial services are primarily based on a single index (NDVI or Thermal) however, the research indicates that an adaptive approach (per crop type, over the growing season, and different regions) is required for success. Future research needs to focus on optimising how the different approaches are combined and translating this into a commercial offering.

The review has identified the following researchers that are currently working on remote sensing, smart sensors, and system control, with which there could be potential for collaboration:

- Christopher Neale[12] is the Director of Research for the University of Nebraska Water for Food Daugherty Global Institute. Christopher specialises in remote sensing. He has recently undertaken work to combine both NDVI and thermal

[11] https://www.lindsay.com/smartpivot/#main-content
[12] https://waterforfood.nebraska.edu/meet-our-people/christopher-neale

remote sensing approaches for irrigation scheduling using an open-source water balance model approach.

- Troy Peters[13] is an Associate Professor at the Washington State University Agriculture Research and Extension Center. Troy specialises in remote sensing and is also working on smart soil moisture sensors (self-learning).
- Stuart Styles[14] is the Director of the Cal Poly Irrigation Training and Research Centre. Stuart specialises in water supply system automation (open channel and piped) and has an interest in the development of open architecture control systems.
- Yafit Cohen[15] is the Head of the Sensing, Information and Mechanisation Engineering department at the Volcani Institute, Israel.
- Offer Rozenstein[16] is the director of the Rozenstein Lab center). The lab specialises in satellite image processing, remote sensing, and crop modelling and is part of the Soil, Water and Environmental sciences division at the Volcani Institute, Israel.

The review has also identified the following USDA project for which there could be potential for collaboration.

> *Research Project:* Advancing Water Management and Conservation in Irrigated Arid Lands[17]
>
> *Objective:* To develop decision support tools and sensing and computing technologies to support improved crop water use efficiency for irrigated agriculture in arid lands.

Note: The review found that the USA appears to be further advanced with its sensor technology research (particularly remote sensing), but Australia (surface and spray) and New Zealand (spray) are more advanced with control and automation.

Unfortunately, there are minimal training opportunities for sensor and telemetry installation and maintenance in Australia (and internationally), beyond a minority of companies that have in-house product specific offerings. Service providers are mainly self-taught and have gained their knowledge and skills through on-job learning.

For the successful adoption of precision irrigation training urgently needs to be developed that includes:

- Design and installation considerations for different sensor and telemetry options
- Basic wiring and trouble-shooting methods
- Commissioning procedures
- On-going maintenance

Part of upskilling service providers is having a set of standards to refer to. Australia has developed Water Information Standards through the Australian Bureau of

[13] https://wrc.wsu.edu/person/peters-troy/
[14] http://www.itrc.org/faculty/styles.htm
[15] https://www.agri.gov.il/en/departments/11.aspx
[16] https://soilmedia63.wixsite.com/offerlab; https://www.agri.gov.il/en/people/1313.aspx
[17] https://www.ars.usda.gov/research/project/?accnNo=432371

Meteorology[18] but these focus on water measurement. New Zealand has developed the National Environmental Monitoring Standards (NEMS)[19]. These standards cover a broader range of topics, from sensor selection and installation, through to data quality coding. They also account for the variation in quality of sensors and installation practices and so can be applied to different scenarios (national monitoring networks through to non-critical farm applications). These would provide useful reference material for any training developed.

The other key challenge for the service industry, which was specifically commented on by most of the farmer interviewees, was the current poor level of after sales-service. What is promised is frequently not delivered. This is a challenging area to address as many farmers initially select technology on price rather than the level of service provision, which drives a 'race to the bottom'.

A project working with the service sector exploring client focused 'whole of product life' business models would be of value. This project should be viewed as a 'catalyst' for changed as opposed to 'providing a solution'. It will help individual companies understand the issues farmers are facing, reflect and then adapt - finding a solution that best fits their business model.

There is potential for collaboration with Irrigation Australia around both the service provider training needs and communicating the need for a greater focus on after-sales service business models.

[18] http://www.bom.gov.au/water/standards/index.shtml
[19] https://www.nems.org.nz/

Research Commercialisation

The service providers interviewed commented on the need for:

- Better targeted and more effective applied research collaborations, including the need for earlier involvement in the research rather than just at the point of commercialisation.
- Improved uptake of research outputs through enabling awareness and their easier integration with existing commercial solutions.
- Greater collaboration between researchers, particularly with remote sensing and system automation research.

Researchers also commented that the competitive funding model in which they operate was not always conducive to collaboration.

Recommendations

1. **Provide pathways for early service provider involvement in research.**
2. **Implement a 'fast-fail' applied research system.**
3. **Increase commercial awareness and access to government and sector research.**
4. **Clearly identify and agree upfront how any potential Intellectual Property is to be treated.**

Many service providers felt their engagement in research was to leverage free product rather than for their practical skills and knowledge. This was frustrating them as they often found the end research was of limited value from a commercial application perspective. The consensus was service providers wanted to be involved much earlier in the research process; helping to inform or co-design the research proposal. It was also noted that service providers need to be timely in their interactions for this to be successful.

Some service providers and researchers commented that the applied research needed to be more adaptive in nature and have much clearer stop/ go points within it. Implementing a fast-fail system would provide for this.

The fast-fail approach focuses on experimenting and learning while trying to reach a desired outcome. It is an iterative process that is strongly connected with agile project management methodology. By quickly identifying and addressing the systems failures this helps more rapidly find the solution. For fast fail systems to be successful researchers should:

- Be enabled to take informed risks.
- Regularly reflect and adapt or stop as appropriate.
- Be encouraged to test solutions as soon as they are 'good-enough', and then learn, adapt, and retest through an iterative cycle.

Fast-fail systems are a proven approach for testing new technology concepts or ideas such as precision irrigation research and development. The challenges for the fast-fail approach are:

- Agricultural research traditionally has a seasonal trial focus.
- It does not sit comfortably with some researchers, particularly those who strive for perfection rather than 'good enough'; it may require strong oversight for its successful implementation.

Many service providers stated they had no idea what research had already been completed or was being undertaken (beyond direct connections with individual researchers). Service providers having a clear understanding of recent, current, and future research is key to enhancing research uptake on-farm.

A simple and effective way for new research to effectively reach a wider commercial audience is 'packaging-up' each project into a clear digestible summary and making this readily available. Most business development managers are not technical, they are also time limited, so developing a 'technology disclosure statement' allows relevant research to be more easily identified. The information provided should include:

- The stage of technology or research development including the estimated work required to bring it to market.
- The potential applications including the vision for the technology and how it could be used.
- A cost-benefit market analysis, including an indication of the competitive landscape, the benefits the innovation creates, alongside the potential market demand and economic value.

Internationally there are entities such as IN-PART[20] that pick-up this information and provide it to potential commercial partners through their intelligent 'match-making service'. However, for irrigation research a simpler more direct approach could be adopted given the limited number of service providers but noting there is a need for wider distribution than the status quo. The recent growAG[19] platform managed by AgriFutures and supported by the Australian RDC's and the Australian Government Department of Agriculture, Water and Environment could provide the pathway for this.

KiwiNet[21] is another unique approach worth noting. All 18 New Zealand public research institutions have established an entity whose goal is to transform Kiwi scientific discoveries into commercially viable products and services. Government funding is provided for this through the PreSeed Accelerator Fund. The Australian Federal government released a consultation paper for improving University Research Commercialisation in February 2021, and the NZ PreSeed Accelerator fund concept is included within this.

[20] https://in-part.com/
[21] https://kiwinet.org.nz/

Some service providers commented that it was difficult to access research outputs once they were made aware of them, and that there was often confusion between Intellectual Property and public good information.

To overcome this research institutions, need to clearly identify any Intellectual Property within the research and provide pathways (as appropriate) for service providers to access it as discussed above.

The Intellectual Property identification process must start prior to the research commencing as this will help prevent confusion and issues arising as the research develops. This would also assist with some of the tensions between researchers under the competitive funding model, helping them to better collaborate.

Appendix A: Literature Review

The first two-links provided are of notable relevance, the first is to a similar project occurring in the USA through the USDA, the second is to a recently published paper that summarises the challenges and opportunities for precision irrigation decision-support and lists all the decision-support tools currently available in the USA through both universities and commercial providers.

	Title	Link	Description	Contact
General	Research Project: Advancing Water Management and Conservation in Irrigated Arid Lands	https://www.ars.usda.gov/research/project/?accnNo=432371	The long-term objectives of this project are to develop decision support tools and sensing and computing technologies to support improved crop water use efficiency for irrigated agriculture in arid lands.	Kelly Thorp, Agricultural Engineer, US Arid-Land Agricultural Research Centre, Maricopa, Arizona, USA
	Challenges and opportunities in precision irrigation decision-support systems for centre pivots	https://iopscience.iop.org/article/10.1088/1748-9326/abe436/meta	Critical challenges for precision irrigation research - data availability and scalability; Quantification of plant water-stress; Model uncertainties and constraints; Grower motivation.	Jingwen Zhang, Department of Natural Resources and Environmental Science, University of Illinois, USA
	Intelligent Irrigation	https://www.waterworld.com/home/article/14071042/inteligent-irrigation	Magazine article discussing the current state of intelligent irrigation in the USA	https://www.waterworld.com/
	Maximising the Value of Irrigation	https://storymaps.arcgis.com/stories/ba955a035f6b4a36a0561fca054da3b5	Report on findings of a 6-year project run by Landcare Research, with Plant & Food Research and the Foundation for Arable Research (FAR), NZ.	Carolyn Hedley, Senior Soil Scientist (Ret), Landcare Research, Palmerston North, NZ.

Sensors and Decision-Making Tools	A cyber-physical intelligent agent for irrigation scheduling in horticultural crops	https://www.sciencedirect.com/science/article/abs/pii/S0168169920319839	A cyber-physical intelligent agent was implemented for irrigation scheduling. The irrigation agent was made up of the perception, actuation, reasoning, and control systems. Crop modelling was used for implementing the heuristic in the reasoning system. The reasoning system estimated irrigation prescriptions with the best Water Use Efficiency.	Andres-F Jimenez, Universidad Nacional de Colombia, Carrera 45 N° 26-85 - Edificio Uriel Gutiérrez, Bogotá, D.C., Colombia
	A review on monitoring and advanced control strategies for precision irrigation	https://www.sciencedirect.com/science/article/abs/pii/S0168169919314826	The advent and rapid successes of the Internet of Things (IoT) and advanced control strategies are being leveraged to achieve improved monitoring and control of irrigation farming. In this review, a thorough search for literature on irrigation monitoring and advanced control systems highlighting the research works within the past ten years are presented.	Emmanuel Abiodun Abioye, Control and Mechatronics Engineering Department, School of Electrical Engineering, University Teknologi Malaysia, Malaysia
	A Smartphone Application for Scheduling Irrigation in Cotton	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2016/ASmartphoneApplicationforSchedulingIrrigationinCotton.pdf	The Cotton Smart Irrigation App (Cotton App) uses an interactive ET-based soil water balance model, including meteorological data from weather station networks, soil parameters, crop phenology, crop coefficients, and irrigation applications to estimate root zone soil water deficits in terms of percent as well as of inches of water.	Wesley Porter, Assistant Professor, Ext. Precision Ag and Irrigation Specialist Crop & Soil Sciences Department, University of Georgia
	A survey on intelligent agents and multi-agents for irrigation scheduling	https://www.sciencedirect.com/science/article/abs/pii/S0168169919326316	Intelligent agents for irrigation scheduling are described as rational entities. Irrigation agents are explained based on systems of perception, actuation, inference, and control. Negotiation, communication, and cooperation are discussed with multi-agent irrigation systems. Considerations, challenges, and opportunities of multi-agent irrigation systems are shown.	Andres-F Jimenez, Universidad Nacional de Colombia, Carrera 45 N° 26-85 - Edificio Uriel Gutiérrez, Bogotá, D.C., Colombia

	An IOT Based Smart Irrigation System Using Soil Moisture and Weather Prediction	https://www.researchgate.net/publication/341272817_An_IOT_based_Smart_Irrigation_System_using_Soil_Moisture_and_Weather_Prediction	Internet of Things (IoT) solutions, based on the application specific sensors' data acquisition and intelligent processing, are bridging the gaps between the cyber and physical worlds. IoT based smart irrigation systems can help in achieving optimum water-resource utilization in the precision farming landscape	S. Velmurugan, Department of Electronics and Communication Engineering, T.J.S. Engineering College
	Efficient Irrigation of Maize Through Soil Moisture Monitoring and Modelling	https://www.frontiersin.org/articles/10.3389/frwa.2021.627551/full	Paper published 2021, added value of the integration between field data and a properly calibrated hydrological model	Matteo Camporese, Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy
	Engineering Adaptations Optimizing IOT in Agriculture	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/Engineering_Adaptations_Optimizing_IOT_HIBBS.pdf	IOT has the unique capability to utilize and combine data from non-proprietary and different resources, such as point-specific data, public or government data, farm, and crop data. This data can combine to not only display data, but to display and report on actionable task items to provide real-time control or make real-time decisions and alarming.	Rob Hibbs, Agricultural Engineer, MeasureTek, Albany, Oregon, USA
	Evaluation of the CSM-Cropgro-Cotton model for the Texas Rolling Plains, Simulation of Deficit Irrigation Strategies for increasing water use efficiency	https://www.ars.usda.gov/ARSUserFiles/40820/Modala2015%20-%20CROPGRO-Cotton%20Texas.pdf	The Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (CSM) CROPGRO-Cotton was extensively tested and then used for evaluating various deficit irrigation strategies for this region	Srinivasulu Ale, Associate Professor, Dept Biological and Agricultural Engineering, Texas A&M University, USA

	IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture	https://www.researchgate.net/publication/339379875_IoT-Based_Smart_Irrigation_Systems_An_Overview_on_the_Recent_Trends_on_Sensors_and_IoT_Systems_for_Irrigation_in_Precision_Agriculture	Due to the recent advances in IoT and WSN technologies that can be applied in the development of these systems, we present a survey aimed at summarizing the current state of the art regarding smart irrigation systems. We determine the parameters that are monitored in irrigation systems regarding water quantity and quality, soil characteristics and weather conditions. We provide an overview of the most utilized nodes and wireless technologies. Lastly, we will discuss the challenges and the best practices for the implementation of sensor-based irrigation systems.	Laura García, Instituto de Investigación para la Gestión Integrada de zonas Costeras, Universitat Politècnica de València, 46730 Grau de Gandia, Spain
	Optimizing Irrigation Scheduling with Limited Water Using the iCrop Decision Support Tool	https://ucanr.edu/sites/calasa/files/287358.pdf	iCrop: Integrated Crop Water and Nitrogen Management	Isaya Kisekka Assistant Professor Departments of Land, Air & Water Resources and Bio-Ag Engineering, University of California Davis.
	Soil water balance models for determining crop water and irrigation requirements and irrigation scheduling focusing on the FAO56 method and the dual Kc approach	https://www.sciencedirect.com/science/article/abs/pii/S0378377420303930	This study reviews soil water balance (SWB) model approaches to determine crop irrigation requirements and scheduling irrigation adopting the FAO56 method. The Kc-ETo approach is discussed with consideration of baseline concepts namely standard vs. actual Kc concepts, as well as single and dual Kc approaches.	L.S. Pereira, LEAF - Linking Landscape, Environment, Agriculture and Food, Instituto Superior de Agronomia, Universidade de Lisboa, Lisbon, Portugal

	Two-dimensional time-lapse imaging of soil wetting and drying cycle using EM38 data across a flood irrigation cotton field	https://www.sciencedirect.com/science/article/abs/pii/S0378377420307666	Understanding the spatiotemporal distribution of soil volumetric water content (θ, m3 m−3) at field level is required to maximise water-use efficiency in irrigated agriculture. Several commercial sensors are available; however, they only provide point-information. To value-add to this soil data, mathematical models can be used in conjunction with proximal sensed data, such as soil apparent electrical conductivity.	Ehsan Zare, School of Biological, Earth and Environmental Sciences, Faculty of Science, UNSW Sydney, NSW, 2052, Australia
	Use of Soil Moisture Sensors for Irrigation Scheduling	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2016/UseOfSoilMoistureSensorsForIrrigationScheduling.pdf	suggested to install 3 sensors at different depths across crop root zone. Crop root distributions across the root zone and crop growth stages should be considered when the sensor readings at different measurement depths are used to determine a threshold to trigger irrigation events.	Ruixiu Sui, USDA-ARS Crop Production Systems Research Unit, Stoneville, Mississippi
	Water in the Cloud: A new system for field water monitoring with Cloud data access	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/Water_In_The_Cloud_EVETT.pdf	The LoRa based node and gateway system for soil water sensor data acquisition and wireless telemetry described provides an effective, low-cost, solar-powered solution for delivering data to the Internet Cloud at a URL that can be accessed by anyone with access rights.	Steven Evett, Research Soil Scientist, USDA ARS Conservation & Production Research Laboratory, Texas
	Wireless soil moisture sensor networks for precision irrigation scheduling	http://tur-www1.massey.ac.nz/~flrc/workshops/12/Manuscripts/Hedley_2012.pdf	Management zones were defined from data layers from electromagnetic surveys and yield maps. Wireless soil moisture sensor networks were then positioned into these zones to monitor wetting and drying events for precision irrigation scheduling.	Carolyn Hedley, Senior Soil Scientist (Ret), Landcare Research, Palmerston North, NZ.
System Control	Advances in intelligent and autonomous systems to improve irrigation and fertiliser efficiency	http://flrc.massey.ac.nz/workshops/14/Manuscripts/Paper_Raine_2014.pdf	An overview of the irrigation and nutrient management tools developed by NCEA along with a focus on current research investigations nutrient and water management control strategies for irrigation systems	Steven Raine & Alison McCarthy, NCEA University of South Queensland

	Effectiveness of Irrigation Water Management Practices for Mid-South Furrow Irrigation	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2018/Effectiveness_Irrigation_Water_Mangement_Practices_HENRY.pdf	The objective of this research was to evaluate the efficacy of Computerized Hole Selection (CHS), Surge Irrigation (SURGE), and Soil Moisture Monitoring (SMM). F	Chris Henry, Associate Professor and Water Management Engineer, Rice Research and Extension Centre, University of Arkansas.
	Evaluating the performance of automated bay irrigation	https://www.researchgate.net/publication/294731658_Evaluating_the_performance_of_automated_bay_irrigation	Demonstrate the application efficiencies achievable through the use of automated, high flow irrigation	J Uddin, R Smith, M Gillies - NCEA, & P Moller, D Robson - Rubicon Water, Australia
	Opportunities for Automation of Surface Irrigation	https://alfalfa.ucdavis.edu/+symposium/proceedings/2018/Khaled%20Bali.pdf	Once a system is designed for maximum efficiency, automating irrigation gates provides additional control measures to achieve the desired efficiency. Surface irrigation automation involves the use of wetting front advance sensors, flumes or flow meters, and electronic timing control gates to determine the irrigation cut-off time.	Khaled Bali, Kearney Agricultural Research and Extension Centre, University of California
	Smart automated furrow irrigation of cotton	https://ascelibrary.org/doi/10.1061/%28ASCE%29IR.1943-4774.0001282	Prototype smart automation system for furrow irrigation. Automation hardware and software for the control of flows throughout the farm open channel delivery system.	J Uddin, R Smith, M Gillies - NCEA, & P Moller, D Robson - Rubicon Water, Australia
Remote Sensing	Applying high-resolution visible-channel aerial imaging of crop canopy to precision irrigation management	https://www.sciencedirect.com/science/article/abs/pii/S037837741831758X	This research proves the applicability of a low-cost digital camera mounted on an easily accessible UAV for crop cover and actual, in-field, ET coefficients determination and irrigation uniformity evaluation.	Assaf Chen, MIGAL Galilee Research Institute, Kiryat Shmona, Israel

Comparison of aerial hyperspectral and multispectral imagery: Case study of nitrogen mapping in Australian cotton.	http://flurosat.com/wp-content/uploads/2020/03/WHISPERS-Paper-Final.pdf	Online workflow for calibration and analysis of the airborne multispectral and hyperspectral data including georectification, derivation of vegetation indices and comparison with time series of the satellite data is reported	Anastasiia Volkova, University of Sydney, FluroSat Pty Ltd
Accuracy of crop coefficient estimation methods based on satellite imagery	https://www.researchgate.net/publication/334305954_Accuracy_of_crop_coefficient_estimation_methods_based_on_satellite_imagery	The crop coefficient (Kc) is a crucial factor in irrigation decision making. The ability to estimate it directly from satellite imagery can immensely assist growers around the globe in their crop monitoring. Direct estimations of Kc from diverse spectral indices, enable the use of various multi-spectral sensors and increase the ability to map relatively small plots (<1.0 ha). The goal of this study was to examine the accuracy of Kc estimations using different spectral indices with different satellite sensors.	O. Beeri, R. Pelta, T. Shilo, S. Mey-ta/, Manna-Irrigation, Gvat, Israel
New Sensing Methods for Scheduling Variable Rate Irrigation to Improve Water Use Efficiency and Reduce the Environmental Footprint	https://mro.massey.ac.nz/bitstream/handle/10179/15751/El-NaggarPhDThesis.pdf?sequence=1&isAllowed=y	Crop indices (NDVI, and canopy surface temperature, Tc) together with site-specific climate data were used to estimate daily crop water use at trial sites between 2017 and 2019. A model-based, decision support software system (VRI–DSS) that automates irrigation scheduling to variable soils and multiple crops was then tested	Ahmed El-Naggar, Massey University, Palmerston North, New Zealand
Comparison of traditional and ET-based irrigation scheduling of surface-irrigated cotton in the arid southwestern USA	https://www.sciencedirect.com/science/article/abs/pii/S0378377415300317	To determine whether the use of ET-based irrigation scheduling methods could improve lint yield and irrigation water use productivity over traditional cotton border irrigation scheduling practices in the region	Doug Hunsake, Agricultural Engineer, US Arid-Land Agricultural Research Centre, Arizona, USA

Cotton yield estimation using very high-resolution digital images acquired with a low-cost small unmanned aerial vehicle	https://www.ars.usda.gov/ARSUserFiles/60663500/Publications/Sui/2016/Huang%20et%20al.%202016_ASABE_59-6-1563-1574.pdf	Remote sensing provides techniques to monitor cotton growth and estimate cotton yield rapidly with coverage of fields and areas at different scales. This study showed that low-altitude remote sensing witha small UAV can be used for reliable cotton yield estimationbased on estimation of plant height by manipulating 3Dpoint cloud data.	Ruixiu Sui, Agricultural Engineer, USDA-ARS Sustainable Water Management Research Unit, Stoneville, Mississippi, USA
Development and Evaluation of UAV-Based Remote Sensing Systems and Methods for Precision Irrigation.	https://www.ars.usda.gov/research/project/?accnNo=428196	The objective of this research is to develop and evaluate unmanned aerial vehicle (UAV)-based remote sensing systems and methods to map plant biotic and abiotic characteristics for precision irrigation.	Ruixiu Sui, Agricultural Engineer, USDA-ARS Sustainable Water Management Research Unit, Stoneville, Mississippi, USA
Dual polarimetric radar vegetation index for crop growth monitoring using sentinel-1 SAR data	https://www.sciencedirect.com/science/article/abs/pii/S0034425720303242	In this study, we have jointly utilized the scattering information in terms of the degree of polarization and the eigenvalue spectrum to derive a new vegetation index from dual-pol (DpRVI) SAR data. We assess the utility of this index as an indicator of plant growth dynamics for canola, soybean, and wheat, over a test site in Canada	Dipankar Mandal, Microwave Remote Sensing Lab, Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, India

Evaluation of different methods of estimating ET for the performance assessment of irrigation schemes	https://www.sciencedirect.com/science/article/abs/pii/S0378377420300974	EEFlux is a good application for satellite-based irrigation performance assessment. Irrigation performance assessment improves using field-specific crop coefficients. The satellite-based ET estimation method should consider the interpolation errors.	Ramiro Salgado, Instituto Nacional de Tecnología Agropecuaria-Estación Experimental Agropecuaria Santiago del Estero, Jujuy 850, 4200 Santiago del Estero, Argentina
Evaluation of remote sensing-based evapotranspiration models against surface renewal in almonds, tomatoes, and maize.	https://www.sciencedirect.com/science/article/abs/pii/S0378377420300639?via%3Dihub	RS-based ETa estimates for three crops were compared to surface renewal ETa measurements. pySEBAL and METRIC performed better under full canopy cover than early in the season. SEBS performed the best among three remote sensing models for daily ETa estimation.	Xue, J. Department of Land Air & Water Resources, and Department of Biological and Agricultural Engineering University of California Davis,
Evaluation of variable rate irrigation using a remote-sensing-based model	https://www.sciencedirect.com/science/article/abs/pii/S0378377418301082	Variable rate irrigation (VRI) strategies were field tested at two locations. One strategy utilized a remote-sensing-based spatial ET and soil water balance model (VRI-RS). The VRI-RS treatment resulted in more irrigation due to water balance drift. Available water capacity was the variable with the greatest spatial variability	J. Burdette Barker, Biological Systems Engineering Department, University of Nebraska-Lincoln, Lincoln, Nebraska
Fuzzy control system for variable rate irrigation using remote sensing	https://www.sciencedirect.com/science/article/pii/S0957417419300491	Variable rate irrigation speed control was enhanced using spatial variability. Increasing or decreasing the rotation speed of central pivot using fuzzy system. Combining edaphoclimatic variables to fuzzy logic can solve problems in irrigation. Expert system using remote sensing can manage the speed control for central pivot.	Willians Ribeiro Mendes, Control Engineering and Automation Department, Federal Institute of Education, Science and Technology of Mato Grosso – IFMT, Brazil

Improvement of the Trapezoid method using raw landsat image digital count data for soil moisture estimation in Texas high plains	https://www.mdpi.com/1424-8220/15/1/1925	Development of an index to estimate soil moisture content. Based on empirical parameterization of the relationship between raw image digital count data in the thermal infrared spectral band and ground cover.	Sanaz Shafian and Stephan J Maas, Department of Plant and Soil Science, Texas Tech University
Monitoring irrigation water use over paddock scales using climate data and landsat observations	https://www.sciencedirect.com/science/article/abs/pii/S0378377418316871	Accurate simulations of irrigation water use through remote sensing. Irrigation depth was successfully simulated for cotton and almond crops. Wine grapes provided less accurate results due to certain management practices. Unknown crop types provided a wide spread of results with potential for calibration. Identification of crop is required for best simulation results.	David Bretreger, School of Engineering, The University of Newcastle, Callaghan, New South Wales 2308, Australia
Phenological corrections to a field-scale, ET-based crop stress indicator: An application to yield forecasting across the U.S. Corn Belt	https://www.sciencedirect.com/science/article/pii/S0034425721000559	The results of this study demonstrate that remotely sensed ET at high spatiotemporal resolution can convey valuable water stress information for forecasting crop yields across the Corn Belt if interannual phenological variability is considered.	Yang Yang, USDA ARS, Hydrology and Remote Sensing Laboratory, Beltsville, Maryland, USA
PICS: Post-image-collection specification for Agricultural remote sensing	https://s3.amazonaws.com/aggateway_public/AgGatewayWeb/News/CommunicationsKit/AgGateway_PICS_Flyer_72219.pdf	PICS seeks to take the friction and guesswork out of using remote sensing in agriculture. It uses an existing format (GeoTIFF) and metadata tags defined within it to specify what images mean.	https://www.aggateway.org/

Reflectance-based crop coefficients REDUX: For operational evapotranspiration estimates in the age of high producing hybrid varieties	https://www.sciencedirect.com/science/article/abs/pii/S0378377417301026	Paper analyses the basal crop coefficient. Soil adjusted vegetation index and Leaf area index based on the non-liner relationships proposed by Choudhury (1994). The resulting relations ships are assimilated into a remote sensing-based soil water balance model.	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
Remote Sensing and GIS Techniques for Assessing Irrigation Performance: Case Study in Southern California	https://www.researchgate.net/publication/324674315_Remote_Sensing_and_GIS_Techniques_for_Assessing_Irrigation_Performance_Case_Study_in_Southern_California	potential of remotely sensed data in addressing spatially distributed irrigation equity, adequacy, and sustainability. The results showed that remote sensing and GIS techniques can be combined to provide a comprehensive picture of irrigation performance across irrigation schemes.	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
Research Project: Development of Methods for Creating Variable Rate Irrigation Prescriptions	https://www.ars.usda.gov/research/project/?accnNo=430848	The objective of this research is to conduct analysis and integration of soil properties and plant water stress for creating variable rate irrigation prescriptions.	Ruixiu Sui, Agricultural Engineer, USDA-ARS Sustainable Water Management Research Unit, Stoneville, Mississippi, USA
Research Project: Collaborative Research and Outreach to Facilitate Cotton Production in Thermo-limited Regions of the Southern Ogallala Aquifer Region- Texas Tech. Ongoing	https://www.ars.usda.gov/research/project/?accnNo=439128	To conduct long-term research for irrigated cotton production in thermo-limited regions of the northern Texas Panhandle and Southwest Kansas	David Brauer, Director, USDA Conservation and Production Research Laboratory, Bushland, Texas, USA

Research Project: Spatiotemporal Decision Support Systems for Recognizing Variability and Managing Precision Irrigation in Field Crops	https://www.ars.usda.gov/research/project/?accnNo=437535	Characterize the spatial variability within centre-pivot irrigated fields to produce irrigation prescription maps for optimal crop water requirements using precision irrigation.	Susan O'Shaughnessy, Agricultural Engineer, USDA Conservation and Production Research Laboratory, Bushland, Texas, USA.
Site-specific irrigation management in a sub-humid climate using a spatial evapotranspiration model with satellite and airborne imagery	https://www.sciencedirect.com/science/article/abs/pii/S0378377419309552	Evaluate unmanned aircraft systems and the data they produce for VRI, and to quantify the potential of VRI in terms of relative crop and water response	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
Soil water content estimation using a remote sensing-based hybrid evapotranspiration modelling approach	https://www.sciencedirect.com/science/article/abs/pii/S0309170812002709	paper a hybrid ET approach is applied to irrigated and non-irrigated cotton fields at the BEAREX08 experimental site using airborne remote sensing inputs under highly advective conditions, taking advantage of the available root zone soil water content measurements for verification of model output.	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
Temporal and spatial variations of irrigation water use for commercial corn fields in Central Nebraska	https://www.sciencedirect.com/science/article/abs/pii/S0378377419308030	Application of a remote sensing-based soil water balance for the study of water use in agricultural areas	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA

	Use of Satellite Imagery to Calibrate Crop Coefficient Kc for Irrigation	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2019/Use-Satellite-Imagery-to-Calibrate_Han.pdf	Satellite imagery has potential for using on adjustment of irrigation forecasting/recommendation. The application effectiveness of using satellite imageries may depend on which vegetation index is used and the Kc adjustment timing and magnitude. Solely depends on satellite imageries for irrigation recommendation is not mature yet. The quality of imageries will affect accuracy (e.g., cloud cover). Kc is still the most effective parameter for irrigation scheduling.	James Han, FieldNET Advisor Specialist, Lindsay Corporation.
	Variable Rate Irrigation of Maize and Soybean in West-Central Nebraska Under Full and Deficit Irrigation	https://www.frontiersin.org/articles/10.3389/fdata.2019.00034/full	A remote-sensing-based evapotranspiration model was implemented with Landsat imagery to manage irrigations for a VRI equipped centre pivot irrigated field located in West-Central Nebraska planted to maize in 2017 and soybean in 2018	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
	Water balance of irrigated areas: a remote sensing approach	https://www.researchgate.net/publication/230551842_Water_balance_of_irrigated_areas_A_remote_sensing_approach	to summarise the results of previous studies in quantifying water balance components of irrigation schemes, as well as to present challenges and opportunities of conducting such research projects.	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
	Water productivity and crop yield: A simplified remote sensing driven operational approach	Published in Advances in Agricultural and Forest Meteorology 249 (2018)	Simplified remote sensing approach to assist crop growth models in reproducing actual processes in the field by relating satellite based remote sensing data and key canopy biophysical parameters	Chris Neale, Daugherty Water for Food Institute, University of Nebraska, USA
	Thermal remote sensing for drip irrigation management in cotton	https://www.agri.gov.il/en/pages/1078.aspx	The results of multi-year studies on thermal-remote sensing for irrigation management imply that remotely sensed thermal data can replace manual measurements of water status, with the same or higher yields and similar or less amounts of water application. despite the imperfection in the estimation of LWP by the thermal-imaging, the latter has the advantage of measuring many more of the plants, leading to better irrigation decisions.	Yafit Cohen, Volcani Institute, Israel

Data Integration	ATLAS: Agricultural Interoperability and Analysis systems	https://www.atlas-h2020.eu/objectives/	ATLAS will build an open, distributed, and extensible data Interoperability Network, based on a service-oriented architecture which will offer a high level of scalability from a single farm to a global community.	
	Data sharing in agriculture. Towards a European agriculture data space.	https://aioti.eu/wp-content/uploads/2020/07/Report_Data_Sharing_in_Agriculture_Online_Webinar_10.06.2020_Final.pdf	The overall objective of the workshop is to gather views from different EU stakeholders on current experiences and possible implementations of data sharing in the agri-food sector, looking forward to the implementation of a European-wide agriculture data space in line with the European Strategy for Data.	
	FAIRshare - Digital tools for farm advisors	https://www.h2020fairshare.eu/about-fairshare/	Data base of the digital tools and services used in the EU	
	Digital Transformation of Agriculture through the Use of an Interoperable Platform	https://www.mdpi.com/1424-8220/20/4/1153	he objective of this study was to create an open and interoperable platform based on standard interfaces and protocols to enable the integration of heterogeneous sources of information, while ensuring interoperability with other third-party solutions for exchanging and exploiting such information. Standard and open interfaces and protocols form the basis of the platform, thereby unifying all information in a single data model, which facilitates the better use and dissemination of information. The system was fully instantiated in a real prototype in an irrigation community; the software improved water irrigation management for the farmers connected to the platform.	Juan Antonio López-Morales, Department of Information and Communications Engineering, Computer Science Faculty, University of Murcia, Spain
	Precision Irrigation Through Data	https://s3.amazonaws.com/aggateway_public/AgGatewayWeb/News/CommunicationsKit/AgGatewayPAIL_72219.pdf	Effective irrigation applies the right amount of water at the right time in the right place, and requires inputs such as weather data, soil water content, and plant-based sensors. Scaling this up requires a lot of accurate, interoperable data, but the multiple incompatible formats used by different manufacturers and organizations have been a key barrier to farmers adopting precision irrigation technologies.	https://www.aggateway.org/Home.aspx

	Waterbit - automated rice flooding system	https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2019/Timed-Flooding-Yields-Significant-Gains_Chastaine.pdf	Integrated management system for dry farmed rice, controlled flooding	www.waterbit.com
Agronomy	Determining optimum irrigation termination periods for cotton production in the Texas high plains	https://www.ars.usda.gov/ARSUserFiles/40820/Ale2020%20-%20irrigation%20termination%20Texas%20cotton.pdf	The objective of this study was to determine optimum termination periods for conditions using the decision support system for Agrotechnology transfer, Cropgro-cotton model.	Srinivasulu Ale, Associate Professor, Dept Biological and Agricultural Engineering, sriniale@ag.tamu.edu
	Irrigation rate and timing effects on Arizona cotton yield, water productivity, and fibre quality	https://www.sciencedirect.com/science/article/abs/pii/S0378377419322152	The objective of the study was to measure responses of cotton yield, water productivity, and fibre quality to variable irrigation rates and timings for the 2016, 2017, and 2018 cotton growing seasons	Kelly Thorp, Agricultural Engineer, US Arid-Land Agricultural Research Centre, Maricopa, Arizona. USA
Extension	A close examination of the role and needed expertise of brokers in bridging and building science policy boundaries in environmental decision making	https://www.nature.com/articles/s41599-020-0448-x	This research identifies further under-explored aspects of brokering expertise, namely, the multiple dimensions of brokering, transdisciplinary skills and expertise, 'absorptive' uncertainty management and knowledge translation practices.	R. Duncan, Manaaki Whenua Landcare Research, Lincoln, New Zealand.
	Advances in Knowledge Brokering in the Agricultural Sector: Towards Innovation System Facilitation	https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/7519	Innovation brokering is about performing several linkage building and facilitation activities in innovation systems, creating an enabling context for effective policy formulation and implementation, development, and innovation.	Laurens Klerkx, Professor Knowledge, Technology and Innovation Group, Wageningen University, Netherlands.

	Agricultural knowledge, linking farmers, advisors, and research to boost innovation	https://www.agrilink2020.eu/wp-content/uploads/2019/02/AgriLink-conceptual-framework-main-report.pdf	Agricultural innovations, particularly those innovations leading towards more sustainable agriculture, are increasingly seen as emerging in and best advanced by multi-actor learning networks where different stakeholders with their various kinds of knowledge meet and negotiate and institutionalise new meanings and new farming practices.	https://www.agrilink2020.eu/
	The future of knowledge brokering perspectives from a generational framework of knowledge management for international development	https://journals.sagepub.com/doi/full/10.1177/0266666918800174	A report on a discussion group was held with experts in the field of knowledge management for development (KM4D) in April 2017 to consider their opinions on the future of knowledge brokering.	Sarah Cummings, Wageningen University, Netherlands
	The role of innovation brokers in agricultural innovation systems	https://www.researchgate.net/profile/Laurens-Klerkx/publication/236259272_The_role_of_innovation_brokers_in_agricultural_innovation_systems/links/0c960517692a140eec000000/The-role-of-innovation-brokers-in-agricultural-innovation-systems.pdf	The role of innovation brokers in bridging communication gaps between various actors of innovation systems. Based on recent experience in the Netherlands.	Laurens Klerkx, Professor at the Knowledge, Technology and Innovation Group, Wageningen University, Netherlands.

	Western Ranchers' Perspectives on Enablers and Constraints to Flood Irrigation	Rangeland Ecology and management, Vol 73 issue 2 March 2020	Flood irrigation on western rangelands is important for diverse social and ecological reasons, providing forage for many agricultural operations and maintaining many critical wetlands across the region. However, recent debate over the efficiency of flood irrigation and resulting transition to other "more efficient" types of irrigation has put many of the working wet meadows sustained by flood irrigation at risk.	Mary Sketch, Department of Fish and Wildlife Conservation, Virginia Tech, VA 24061, USA
	Informing extension project design: the right tool for the job	https://www.rmpp.co.nz/site_files/13089/upload_files/nzgrassland_publication_2761InformingExtensionDesign.pdf?dl=1	Extension successfully creates change where projects are designed to fit the issues, opportunity, or technology to be implemented, the potential users, and the influences external to the farm team. This study developed a typology of nine extension approaches and provides a framework to identify the extension approaches for sustainable productivity improvements for higher farm profitability.	T Payne & J. Turner, Agresearch, Hamilton, NZ
Other	Infiltration and soil water distribution in irrigation furrows treated with polyacrylamide	https://www.researchgate.net/publication/346101136_Infiltration_and_Soil_Water_Distribution_in_Irrigation_Furrows_Treated_with_Polyacrylamide	Measured the effects of water-soluble anionic polyacrylamide (WSPAM) on infiltration and soil water distribution in different segments of irrigation furrows	Rick Lentz, USDA-ARS, Biological Science Collaborator, Kimberley, Idaho, USA.
	Numerical simulations of the effects furrow surface conditions and fertilizer locations have on plant nitrogen and water use in furrow irrigated systems	https://www.sciencedirect.com/science/article/abs/pii/S0378377419320293#!	HYDRUS is used to evaluate plant nitrogen and water uptake in furrow irrigated systems. Highlight a substantial reduction in deep drainage in furrow irrigated systems. Achieved using an impermeable membrane on the base of the furrow. Reduction in deep drainage results in a substantial reduction in nitrogen leaching.	Keith L. Bristow, CSIRO Agriculture and Food, PMB Aitkenvale, Townsville, QLD 4814, Australia

Decision-making Tools USA	Arable	https://arable.com/	Arable tracks more than 40 weather and plant measurements to give deep visibility into climate variability, crop health, and the decisions they factor into, such as event timing and irrigation.	
	Hortau	https://hortau.com/	Use soil tension sensor data with a simple-to-use mobile platform to provide an irrigation management service	
	Regrow Ag (FluroSense)	https://www.regrow.ag/	FluroSense is a cloud-based crop management and analytics platform that drives planting and growing decisions that boost sustainability and yield.	

Appendix B: Methodology

Web Review Process

1. Google scholar, journal, and conference proceeding searches:
    a. Irrigation
    b. Irrigation sensing technology
    c. Irrigation telemetry
    d. Irrigation data management
    e. Irrigation monitoring technologies
    f. Irrigation decision support
    g. Surface irrigation
    h. Australian irrigation
    i. Automated gate irrigation
    j. Soil moisture monitoring
    k. Soil moisture sensing
    l. Crop monitoring sensing
    m. Cotton irrigation
    n. Dairy irrigation
    o. Rice irrigation
    p. Sugar cane irrigation
2. Articles of interest were summarised to identify key points.
3. Articles cited or that cited those articles were then identified and any of interest were also summarised to identify key points.
4. Authors of articles of interest were contacted and added to the interview process.
5. Articles were provided by CDRC - these articles were summarised to identify key points and again any citing documents or cited documents were also evaluated.
6. As interviews were conducted, researchers and industry people were asked to provide any papers the understood to be relevant to our review. These were summarised to identify key points. Citing and cited articles were also reviewed, and relevant articles summarised.

Interview Process

1. A list of questions was developed to help guide the conversation to ensure interviews covered the key points (see below).
2. Interview began with a list of key people in Australia identified by the SIP2 programme manager.
3. Interviews were then conducted using:
    a. Water Strategies network of relevant contacts both within Australia and internationally.
    b. Contacts identified through the web search (where they were receptive).

4. During the interviews there was a minimum of two people present. One focused on note taking while the other conducted the interview through conversation.
5. Following the interview notes were reviewed to ensure they were accurate. Key points were then summarised to help identify the themes to present in the report.

Service Industry Interviews

Introduction

- What Product or service do you provide? Link to the table of categories
- What level of service do you provide? (People on the ground and roles)
- How long has your business been established?

Industry context

- What area do you cover?
- How big is your company?
- Where do you sit in the industry?
- Who do you work alongside?
- Who are your main competitors?

Research and Development

- What Research and Development are you doing currently/ have planned?
- What is the science behind your product? (Including any collaboration)
- What papers have been produced/ independent research has been undertaken relating to your product/ service?
- What level of trials do/ did you undertake before you commercialised your product or service?

Irrigator context

- What are the barriers to irrigator uptake?
- What are the challenges you find with irrigator uptake of your service?
- Can you please provide us with a farmer reference?

Value

- What is the value you provide to the farmer? (Including both economic and non-economic - risk mitigation, environmental benefit…)
- What is your sales pitch?
- What support training do you provide for clients? Do you collaborate with any extension providers/ consultants?

Collaboration

- Do you collaborate with any public sector organisations/ universities?
- Do you have any commercial research partners and if so, who are they?

Farmer Interviews

Intro

- What type of farm do you have?
- How big is your farm? (Total and effective hectares)
- What is your irrigated area?
- What type of irrigation do you have?
- Where is your water sourced from?

Products/services

- What technology do you have on farm?
- Why did you choose the products and services you currently have?

Value

- What has/ has not worked?
- Do you use the data you are currently collecting? How do you use it?
- What training/ support have you received?

Gaps

- What technology would you like to have on farm?
- Where do you see there are gaps in the market?
- What support would you like to help you with the adoption of precision irrigation?

Researcher/ Sector/ Service Industry Interviews

Interviewee

- What is your current role?
- What are you researching? (Current and previously)
- What have you published papers on in the past?
-

University or research body

- Where do you perceive you fit in the irrigation industry?
- What commercial partners do you have for research projects?
- Do you have any commercial products/ services?
- What are the challenges you face for commercialisation?
- What is the future you see of the technology industry?
- What training or extension do you provide? (To service providers and farmers)