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Final report

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Contents

1 Acknowledgments

The core VIA team has been a strong and committed unit that has faced and overcome many obstacles over many years: Matthew Driver, Simon Dyer, Luan Steyn, Divan de Vaal and Grethe Nel.

Our Country partner leaders have been excellent and always provided full support: Isaac Fandika, Geoffrey Mwepa and Bezzel Chitsungo.

Our country managers, including Jona Chikankheni and Herbert Kumwenda have done a brilliant job and always gone the extra mile.

Countless farmers joined the VIA and their creativity, courage and commitment has amazed us.

I am grateful for the soil physics laboratories I've been in over my three plus decades at CSIRO and for the wonderful mentors and teachers in the world of turning water into food.

Few funding bodies would invest in a new to world technology, because the chances of success are so slim. ACIAR took that chance back in 2013 and have stayed the course. In the book “40 Years of ACIAR” it states: “The Chameleon soil water sensor is one of the most novel and transformative pieces of technology to arise from ACIAR-supported research (p102)”. Today the VIA is much more than a Chameleon sensor, but it had to start there.

2 Executive summary

The Virtual Irrigation Academy (VIA) has designed, developed and scaled a suite of tools for monitoring water, nitrate and salt, with a focus on smallholder irrigators. The tools give output as colours and the colours represent thresholds for action. Data is presented as colour patterns, which highlight water and solute dynamics, such as under and over irrigation, nitrate leaching and salt accumulation. Colour is a universal language that connects the knowledge domains of scientists and farmers into a unified learning system.

The VIA is built on two monitoring tools. The first tool is the Wetting Front Detector (WFD) which automatically collects and stores a soil water sample from the rootzone. This water sample is used for monitoring nitrate and salt.

The second tool is the Chameleon sensor. This sensor displays the water stress a plant is experiencing and whether it needs to be irrigated or not. Water, nitrate and salt management are intertwined, and together dictate the short-term profitability and longer-term sustainability of irrigated areas.

Around these tools we built other equipment - the Wi-Fi reader, the Chameleon Card and the Chameleon salt meter. Data can be sent by mobile phone to the VIA platform to create the colour visualisations, and data analytics allow for high order insights into irrigation scheme performance.

Experience from thousands of smallholder farmers in many countries has shown that irrigators can interpret basic patterns and take appropriate action. The most common experience was that farmers saw that their fields were wetter than they expected because the sensors stayed blue. For farmers with Wetting Front Detectors, the rapid change of the nitrate test strip from high to low nitrate also made a dramatic impact. Many farmers were able to connect these two observations i.e., too much water keeps the Chameleon blue and leaches the nitrate. Skipping scheduled irrigation days not only saved water but frequently resulted in increased yields. With more water left in the scheme canals, conflicts over water were addressed.

What sets the VIA apart from many other R&D projects is that there was huge demand for our products and services while we were still in the midst of the R&D phase. In response, the VIA set up a global beta test driven by the twin approaches of pushing out Minimum Viable Products as quickly as we could and responding to User-led Design. The VIA beta test helped to refine the products and generated funds which were used to establish a sensor building factory in Pretoria.

The next step of setting up a VIA business was problematic. The problem was not that we needed to commercialise a product. There are well established pathways for doing that. Our problem was that we needed to protect the IP so that it would benefit our partners in Africa who helped create it. We needed to create a business from a publicly funded R4D project that was explicitly pro-poor.

The VIA became a non-for-profit entity in February 2022, with the purpose of serving smallholder irrigators earning less than $5 per day.

3 Background

This is a project final report. But, within a few weeks of exchanging contracts in June 2019, it was clear the VIA had already burst the boundaries of the project documentation. The contract was varied twice but even this did not keep pace with what was happening on the ground.

Today the VIA is a not-for-profit business with tens of thousands of its products sold into over 20 countries. It runs a factory in Pretoria, South Africa, a new sensor production line in Malawi and operates through numerous partnerships and MoUs.

Many people would rate the VIA as highly successful, although its longer-term prospects are by no means certain. What everyone can agree on is that the VIA has been disruptive. It has been disruptive on smallholder irrigation schemes, disruptive to research agendas, disruptive to organisational norms, and disruptive to business and commercialisation strategies.

The story of the VIA needs to be told, but the story is still unfolding, and no single perspective can capture it. I have chosen to write this report in the first person to make clear this is my perspective. Of course, many other people have played key roles in the journey.

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The second tool is the Chameleon sensor. This sensor displays the water stress a plant is experiencing and whether it needs to be irrigated or not. Water, nitrate and salt management are intertwined, and together dictate the short-term profitability and longer term sustainability of irrigated areas.

Around these tools we built other equipment - the Wi-Fi reader, the Chameleon Card and the Chameleon salt meter. Then there are the colour visualisations, the data systems, and the analytics.

The above is straightforward to report on.

What sets the VIA apart from many other R&D projects is that there was huge demand for our products and services while we were still in the midst of the R&D phase.

How were we to respond to such demands?

I have worked in Africa for 33 years. I have been involved in many projects and wrote most of them up as successful. I have been associated with many more projects, reviewed innumerable journal articles and attended many conferences. Success appears to be everywhere. Yet on the ground - in the real world of a smallholder irrigators - progress is faltering at best. Why the disconnect?

Our team leader in Zimbabwe, Eng Bezzel Chitsungo, is the Director of the Department of Irrigation, based in Harare. He recently presented a paper entitled “Curse or Blessing: are smallholder irrigation schemes doomed to succeed”. The implication is that donors, academics and the local agencies are papering over the cracks. Many interventions can work during the project cycle, but there is little to show after the funds stop flowing. While grateful for the support of donors, the result can be that the local agencies are left to pick up the pieces when the project cycle moves on.

This became our challenge. Would the recommendation for this final report be that someone else should build a sensor factory, drop the price five-fold and use our fledgling data systems to drive change through the smallholder irrigation sector?

To start near the beginning.

It was 2014 in southern Tanzania when the first Chameleon sensor and WFD were installed together on a smallholder scheme. There was much excitement amongst farmers and advisors around the ‘colour output’ from the sensors. A couple of years later we interviewed the farmers. They told us they had made major changes to irrigation management because:

“when the Kinyonga stays blue, the Kibandera will turn white”.

Kinyonga is Swahili for a Chameleon and a continuously blue Chameleon sensor means the soil is too wet. Kibandera is Swahili for the indicator flag of the WFD. When the nitrate strips dipped into the water sample from the WFD turns from purple to white, the crop will be nutrient deficient. In this simple phrase, the farmer had nailed the biggest problem of smallholder irrigation. Irrigated fields are kept too wet, and nutrients are washed out.

When the paper was published from this scheme a few years later, it showed that the yields had gone up by 30%, the water consumption down by 65% and the conflict between upstream and downstream water users decreased by 83% (Mdemu et al 2020).

Twenty farmers started by *monitoring* water and nitrate and quickly *learned* about the interplay between over-irrigation and leaching. The knowledge spread from these twenty to most of the 200 irrigators on the scheme, resulting in a scheme level transformation. At first, we thought we were just making monitoring tools. Then we found that monitoring started a social movement that changed the *governance* of water. The story of the Kinyonga and Kibandera has now been repeated many times in many languages. The deep lessons of over-irrigation arise *de novo* from the bottom up in scheme after scheme, country after country. It was experiences such as these that led to the title for VIA Phase 2 “From monitoring, to learning to governance”.

VIA Phase 2 continued with a similar mode of engagement – providing free equipment to a subset of farmers on an irrigation scheme – but expanding to many different schemes. This allowed us to test the VIA concept across a wide range of diverse irrigation scenarios.

At the same time, news about the VIA was spreading and we started getting requests for equipment from other research teams. This was too good an opportunity to miss. Success in our own projects was one thing - with our own trained staff an email away and being able to replace any equipment failures. We thought that being successful in other peoples’ projects was the real test.

And so our global beta test was born. We backed ourselves that we could make enough sensors, solve problems fast enough, support the users and somehow break even financially.

VIA Phase 2 was designed to facilitate scaling, starting with our production line in Pretoria. There was much progress on all fronts. But within six months we faced the same problem as everyone else. The COVID lockdown meant we did not meet any of our African teams face-to-face until the three years into the project, which hampered rollout and some of the co-design of our data products.

At the same time, we totally underestimated the difficulty of setting up a VIA business that could underpin the scaling in LMICs. Although all parties agreed that this was essential – and were supportive in principle – there was no clear pathway. With hindsight we realise that the problem was not in setting up the business. It was that we wanted to set up a pro-poor business, because we knew the prices our target audience could afford.

The mid-term review of this project was held in November 2021, and considered an extension to the current project, both because of COVID delays and because of the impasse in the transfer of IP to a business venture outside of CSIRO that could facilitate scaling.

The review team correctly concluded a VIA business – when established - would not be a financially viable entity by the project end date of June 2023. They stated:

"*ACIAR and the project team find themselves at an inflection point. Whilst great research and product development has been achieved on the technology side, the scaling, data analytics and commercialization is lagging. If the main aim of the project is ensuring commercial viability of VIA post project (including the extension to 2024) then it will be important to review the variation proposal, focus on the low hanging fruits, redirect research and data analytics to support the business models and commercialization of VIA."*

A costed extension to 2024 was recommended with a focus on the 'low hanging fruit'. The focus would be on tailoring the data analytics to large development partners who needed data on the performance of irrigation schemes. We had been in discussion with both IWMI and the World Bank around upscaling VIA data to develop whole of scheme metrics on scheme performance. Such projects were viewed as the most likely source of revenue post 2024.

In addition to the proposed extension, the VIA team were invited to submit a concept note for a VIA Phase 3 in March 2022. This would focus on the same issue as above, and specifically would work with other ACIAR funded projects that relied on VIA data. ACIAR had funded projects in which the VIA suite of products was used in Pakistan, Vietnam, Indonesia, Fiji, Tonga, Kiribati and India. In some of these the VIA team had a role, but in most the VIA provided pro-bono services. A VIA phase 3 would – among other things – continue to support these projects which were taking the VIA to both new areas and new applications. The extension and phase 3 proposals were not approved for funding.

4 Objectives

Project Objectives (as stated in original proposal)

Objective 1: On-going development and refinement of the VIA tools and platform to make it more robust, cost effective and user-friendly.

Objective 2: Increase the capacity and reliability of the Chameleon production line in Africa, not only for this project, but also for the growing community of VIA users worldwide.

Objective 3: Build cost-effective ways to roll out the VIA and obtain quality-controlled field data as the VIA operates at larger scale.

Objective 4: Develop the data analytics that capture the value proposition for each of the five 'clients' of the VIA.

Objective 5: Create the business models and organisational structures that can deliver the VIA irrigation learning and governance platform.

VIA Phase 1 successfully piloted most of the key features of the VIA. But as our external reviewer sagely pointed out *"The pilot never fails, and the pilot never scales".*

Phase 1 was a successful pilot of the VIA tools and the data system. But it was not scalable outside of a research environment. In the R&D business - the D part is more convoluted than the R, takes longer, has more people involved, is more expensive and comes with no guarantee of success.

Objectives 1 and 2 were designed around the scaling question. For example, we knew Chameleon sensors worked in a research environment. The question was could we make tens of thousands at a cost-effective price whilst retaining the same high quality?

Objective 3 addressed a key bottleneck – as more people got involved through the global beta test, we had to build better training and support systems.

Objective 4 was addressed in depth by the mid-term review as the focus of an extension between July 23 and Dec 24. This did not materialise and so we will report less on Objective 4 in this report.

Objective 5 is needed to enable everything else, otherwise the VIA would end on 30 September 2023.

Although the objectives above were retained through the project, there were two variations, reflected in the activities.

The first variation (no cost) was a request from ACIAR to review all activities in light of disruption through COVID. For a project like this, with a huge amount of on-ground work, training and development of the production line in Africa, this was extremely disruptive. The decision was to shift resourcing of current deliverables towards building more on-line resources, such as the website and Water School.

The second variation came towards the end of the project and came with a $120K budget to pioneer the establishment of a production line in Malawi. The activities in Objective 5 were also changed from delivering business models to delivering a business.

5 Methodology

The five objectives have different methodologies.

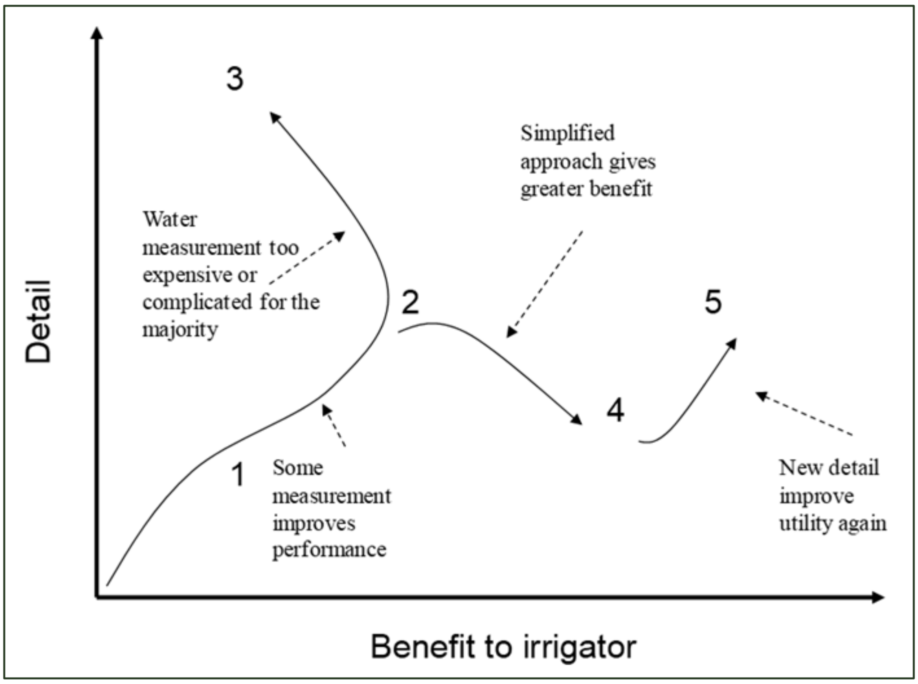
Objectives 1 and 2 follow the design philosophy of Requisite simplicity i.e. simplicity in design is reached not when there is nothing more to add, but when there is nothing more to strip away.

The following section is reproduced from the paper “Sensors that display colours as thresholds for action” and outlines this design philosophy.

The concept of Requisite Simplicity (Holling, 2001) provides a way of linking the complexity of a system with the constraints of those faced with making management decisions, in this case around irrigation. Figure 1 explores the relationship between the cost of implementing a new irrigation technology and the benefit to the irrigator. For an irrigator to benefit (increase yield per unit of water), they must engage with some of the ‘detail’ around soil water dynamics. For example, an irrigator may choose to dig a hole and observe ‘soil wetness’ before making a decision, and so move to position 1. They have engaged some of the detail and derived some benefit. Next, they install soil water sensors, engage more detail and derive more benefit as they move towards position 2.

Up to position 2, there is a positive correlation between expending more effort or expense (i.e. engaging more detail) and deriving more benefit. It seems reasonable that continuing along this trajectory will bring even more benefit. The irrigator now installs multiple sensors at different locations and depths providing hourly data. From a management perspective, more data from more places more often should improve decision making. This might be true if the irrigator could distil and respond to all the new information. But irrigated fields are variable, water may not be available on demand, and farmers have competing priorities. In many cases the irrigator has engaged more of the detail but has derived less benefit and is on the trajectory from point 2 to 3.

Point 2 is the place to re-frame the problem. Re-framing involves simplification or stripping away the detail that is not required i.e., the journey from point 2 to point 4. However, care must be taken to ensure that simplification does not lead to a simplistic response, which in turn leads to error. A Requisite Simplicity finds the middle ground, allows us to act, generate new understanding and provides a means for structured learning (Stirzaker et al. 2010).



The monitoring tools described below were developed by engaging smallholder irrigators in the process of user-led design over many years. The aim was to develop tools that gave information that was cost effective and to provide it in a way that the decision maker could understand. This 're-framing' of the irrigation question is described in Section Two, where each of the four monitoring tools is evaluated from a simplistic and detailed perspective to distil the requisite simplicity. Each tool is described under four subheadings as follows:

i) Description: what the tool measures
ii) Simplistic interpretation: too little detail that may to lead to error
iii) Detailed interpretation: information useful for scientists, not necessarily for managers
iv) Requisite Simplicity: information needed by managers to take action and continue learning

The refinement of the sensors (Objective 1) and the development of production line for scaling (Objective 2), had proceeded along two fronts. First, we bought into the concepts of Minimum Viable Products (MVPs) and User-led Design from the start. According to the proponents of MVPs, the product should be released for beta-testing when the developers are still terrified of failure. The benefits of MVPs are that changes in direction can be made early before the design is set in stone. User-led design means we tried to get as much equipment to as many people as possible for field testing and feedback.

Our second front was a sophisticated on-line quality control process through which every sensor on the production line had to pass. This meant we could continually tweak the designs and assess the performance without expensive and lengthy experiments. Essentially we were juggling four variables i) the cost of components ii) the time to build iii) accuracy of the sensor iv) longevity of the sensor.

Objectives 3 and 4 revolve around how farmers, extension workers, researchers and managers can learn together to govern common pool resources. The VIA has drawn inspiration from many sources of which just a few are listed below.

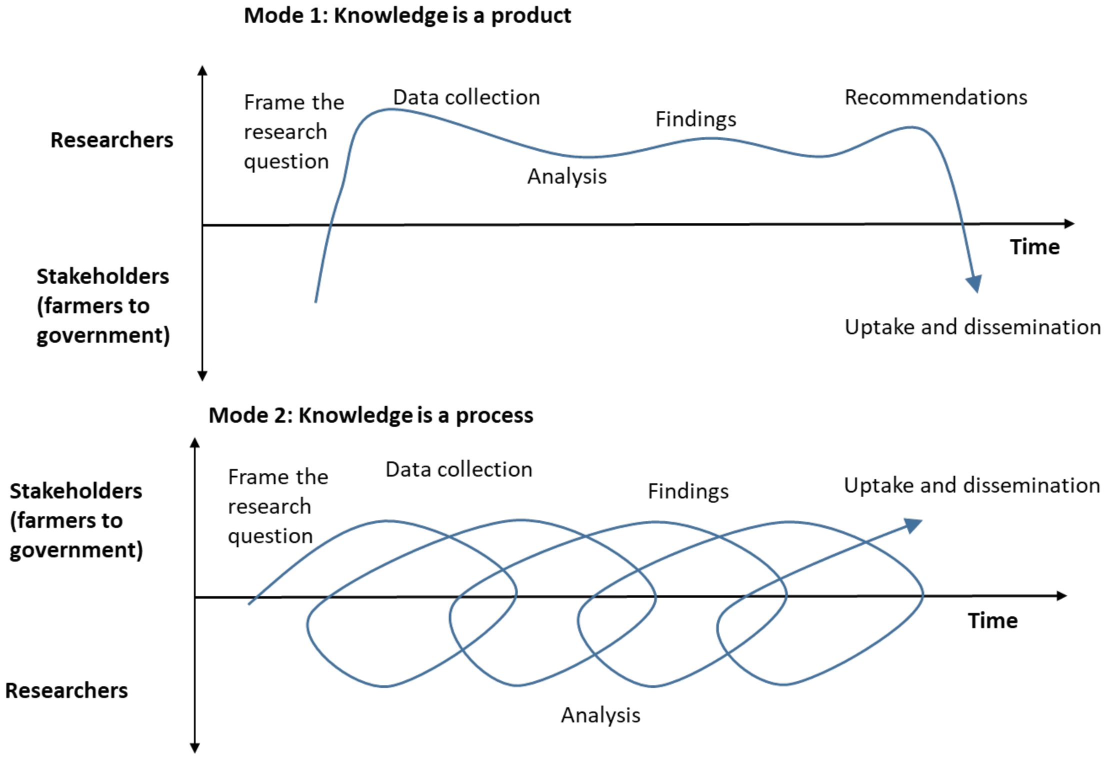
The overall VIA methodology is perhaps best described by the Mode 1 and Mode 2 forms of knowledge production as originally proposed by Gibbons et al. (1994). Mode 1 research is carried out in the context of the specific academic disciplinary context with the aim of producing new reliable knowledge. Mode 2 research involves the application of knowledge in the problem context, usually in a transdisciplinary setting.

	Mode 1	Mode 2
Context	Scientific context	Problem context
Focus	Expert centred	User centred
Purpose	Reliable knowledge (Transferable)	Implementable knowledge (Useful)
Organisation	Planned	Exploring
Quality control	Peer review (It's correct)	Experiential (It works)
Validation	Journal	Societal change

(from Gibbons et al 1994)

The development of the VIA suite of monitoring tools and the VIA platform itself primarily involves Mode 1 research. The application of the VIA in small-scale irrigation schemes is Mode 2 research. The challenge in the VIA project is being able to work in both modes simultaneously, and being able to switch between these two modes according to the nature of the problem. The colour visualisations on the VIA platform connect mode 1 and mode 2. Farmers and researchers engage the patterns on the VIA, which then allows for a structured learning process.

Next, we make a clear distinction between knowledge as a product and knowledge as a process (Ison et al., 2011). Our Mode 1 research has guided the development of the sensors, readers and VIA platform. We follow the accepted 'rules' of science by clear framing of the research problem, developing techniques for running experiments, rigorous analysis of data and application of findings into our products. However, when we engage farmers (and extension workers), the roles of the stakeholders and researchers are flipped. Now farmers frame their problems, collect data, try to work out what it means and apply what they can. The role of the researcher is to participate in this learning journey.



(from Ison et al 2011).

We have found that many researchers find this swapping of roles extremely difficult. As we currently witness the VIA being adopted by other agencies and funders, we repeatedly see the approach of "knowledge as a product" (top diagram) dominating the roll out.

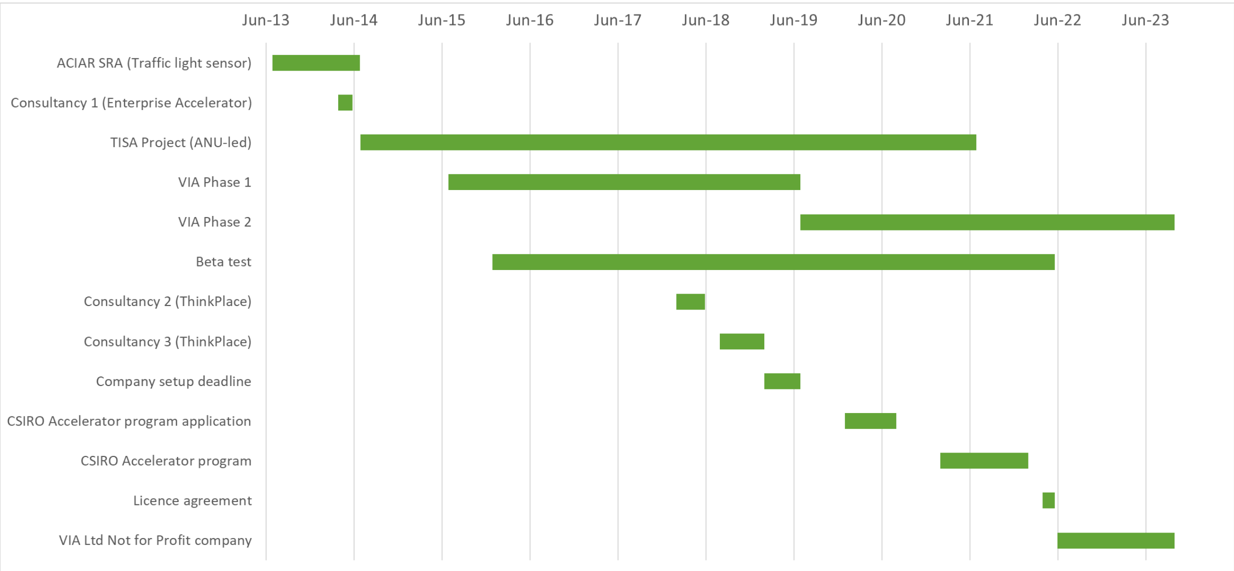
Other frames we bring to the VIA include Adaptive management, starting with the work of Holling, 1978; Lee, 1993; Walters, 1986. Adaptive management is a way of getting around the dilemma of delaying decisions until we've done enough experiments to understand everything we think we need to know. It employs real-life management of the system as a whole and turns it into an experiment by asking the right questions, implementing decisions, collecting the right data and learning from the experience. Adaptive management challenges the positivist view of science as the only producer of reliable knowledge (Ziman 2000) and incorporates the local and experiential knowledge, as well as the values of those charged with managing the resource. To distinguish adaptive management from simple trial and error, considerable effort must be put into documenting our actions and their consequences, which is what the VIA is all about.

The 'knowledge conversion' idea starting with the work of Nonaka et al., 1995 has also provided a useful framing. Many of the famers we work with have low literacy, but possess a rich experiential knowledge borne of years of trial and error that is shared face to face with those they trust. This is tacit knowledge - knowledge that is not usually available to outsiders, such as a research team. However, the Chameleon patterns make this tacit farmer knowledge explicit, and when combined with crop yields, we can evaluate the success of different strategies. We can also compare this new explicit knowledge with explicit knowledge drawn from other domains, such as results generated from research stations. This sparks ideas and experimentation which in turn generates more tacit knowledge, and so the cycle continues in an upwards spiral.

Finally, the concept of double loop learning helps us to break out of the existing framework by challenging its underlying assumptions (Argyris and Schön, 1978). Many irrigation schemes inherited an irrigation schedule handed down by those who designed and built the scheme. This schedule was based on a set of calculations around soil type, crop type, rooting depth and average weather conditions, with the aim of irrigating before crops experience any water stress. Single loop learning occurs when farmers act out of this commonly accepted framework and if plants do not wilt, the framework appears to work. Since the farmer's fear of under-irrigation and potential yield loss transcends concerns over excessive irrigation, the basic framework persists, even though it delivers a mediocre outcome. A strong finding from the VIA is that many farmers have learned, by measuring soil water and nutrients together, that over-irrigation is one of their biggest problems, and they can increase yields by reducing irrigation and hence leaching.

Although these more social science-oriented approaches informed the design, development and deployment of the VIA, we do not explicitly provide social science data in this report (other than the final outcomes). At one stage we put a big effort into the SenseMaker, a narrative-based research methodology that enables the capture and analysis of a large number of stories in order to understand complex change https://thecynefin.co/sensemaker/. The SenseMaker approach potentially offers a methodological breakthrough for recognising patterns and trends in perceptions, behaviours and relationships that are not captured in traditional survey techniques. However, the data we produced did not deepen our insights beyond what we already knew around yield changes, water saving, time saving and conflict reduction.

Finally, the journey of creating an explicitly pro-poor company was a long one (Objective 5). It involved multiple consultancies and workshops, our global beta test driven by User-led-design and MVPs and participating in a year-long accelerator program over a period of 8 years.



The timeline for creating a pro-poor business to help farmers earning less than $5 per day improve their irrigation practice and to govern common pool resources.

6 Achievements against activities and outputs/milestones

Objective 1: *On-going development and refinement of the VIA tools and platform to make them more robust, cost effective and user-friendly*

No.	Activity	Output / milestone	Completion date	Comments
1.1	Refinements of Chameleon sensor	Sensor longevity assessment Sensor salt tolerance assessment	June 2020 June 2020	Sensor longevity is an issue in some circumstances. We have tested several physical and chemical protective coats to retard the dissolution of gypsum. The current best candidate is new type of gypsum cement as a third coat around the buffering material; this requires an extra step in the manufacturing process. We envisage the next version will have a geotextile outer coating. We are also in the process of replacing ENIG electrodes due to corrosion. The sensor is affected by salt with the blue to green switch increasing by around 2 kPa per 1 dS/m increase in soil salinity. This is a fairly small change as the response to the colours should change in saline soils (EC > 4 dS/m) and the WFD should be deployed to manage salinity.
1.2	Refinements of Chameleon reader	number of readers built and a catalogue of reported faults from the field and how they have been addressed.	Six monthly assessment	The reader is now undergoing a significant redesign which includes new LCD screen (replacing OLED), faster uploading, USB C charging port and connections to speed up programming. More changes are planned to include Bluetooth and cellular connectivity in addition to Wi-Fi. Reader manufacture has kept up with demand, but the global supply shortage of chips and huge price increases of certain microprocessors is forcing us into a significant redesign.
1.3	On-going development and testing of Chameleon Card	New product Chameleon card launched Aim to increase distribution by 25 % per year	Six monthly assessment	The demand for the inexpensive Chameleon card continues to rise. We are now developing a 'premium card' that can measure a 3-sensor array as well as individual sensors. The latest design has incorporated a fourth light (purple) to indicate saline conditions as in 1.1 above. This alerts the irrigator that salt management (osmotic pressures) are now as important as water management (matric pressures)
1.4	Refinement of VIA platform and Visualisations	Wizards to configure setup on the VIA platform On-line training for different levels of VIA engagement	June 2020 June 2021	Claiming new sensor arrays and setting up crops on farms has been simplified through a Wizard. The Wizard steps the user through claiming, selecting the farm or irrigation bay, the depth of sensors and associated WFDs and assigning the crop and planting date to the array. New videos on the VIA website explain the process of pairing readers and claiming crops. We are now working on distinguishing the difference between products that are fit for research purposes (educated users) and products that can be sold in volume without costly support.

1.5	Development of Chameleon for wet/dry rice	Chameleon for rice that operates under prolonged waterlogged / salty conditions	June 2021	Several partners have used Chameleon sensors in partially flooded situations, which greatly reduces sensor longevity. Longevity has now become a top priority in the on-going research with promising prototypes now being distributed (see 1.1).

Objective 2: Increase the capacity and reliability of the Chameleon production line in Africa

No.	Activity	Output / milestone	Completion date	Comments
2.1	Canberra research productio n line	Equipment developed for production line and standard operating procedures documented Production line producing 7500 increasing at 15% per year	Six monthly assessment Six monthly assessment	Canberra has pioneered the mechanisation of the production line through the 'pick and place' machine for building circuit boards, automatic wire cutter/stripper and new sensor moulds. All this has been passed on to Pretoria and is continuously being improved. We can make around 10,000 sensors per year. The production line is modular, so we could expand rapidly if necessary. After many years of 'scarcity' we can now build sensors faster than we can sell – except for 2022 when we ran out of stock. The focus needs to shift towards partnerships that can deliver the VIA to farmers earning <$5/day. If the funding was in place, sensor production could expand quickly.
2.2	Quality control systems	Quality control metrics Sensors per year with < 3% failure in Canberra and <10% failure in Pretoria	Six monthly assessment	There have been consistent improvements in sensor quality. The key issue is not our production methods, but variability in feedstock coming into the production line. The biggest problem has been the batch to batch variability in key ingredients, such as the sensing material in the centre of the Chameleon. We have done a global search for high quality suppliers and have been able to source two new materials that show huge promise. Even though the QA failure rate is now very low, we still test every sensor for accuracy as part of the reputation of the VIA (which adds significantly to the cost).
2.3	Pretoria commerci al sensor productio n line	To be commercially viable at scale we need to produce and sell 3000 sensor arrays per year	Six monthly assessment	The Pretoria production line can meet this target. We employ two full time engineers, two full time production line workers plus casuals and they are a highly skilled team. The 3000 sensor arrays per year (12,000 sensors) probably keeps the current small factory itself viable, but cannot carry the overheads of running the VIA. Pretoria has also taken over all the reader and card production, freeing up Solutech for more design type work.

2.4	Supply and distribution chains	Business systems and logistics for operating at scale. Web based shops operating in Australia and Pretoria	Six monthly assessment	Numerous R&D projects have seen the value of the VIA and have been keen to include it in their operations. This has been a big benefit in terms of product testing, but also created a huge unfunded 'overhead' where the team provides support to other projects. The VIA desperately needs to secure a large implementation project to cover development and production costs but this has been thwarted by the delay in setting up the business. Major donors (WB etc) cannot engage a research project in their procurement processes.

Objective 3: *Build cost-effective ways to roll out the VIA and obtain quality-controlled field data as the VIA operates at larger scale.*

No.	Activity	Output / milestone	Completion date	Comments
3.1	Develop new website that is 'partner focused'	New website	Dec 2020	A major achievement was the launch of the new VIA website in Oct 2020.
3.2	Develop multi-media training materials	A series of professional videos that explain the VIA tools and how to use them	Dec 2020	We made ten professional "How to" videos around equipment installation and use, and five videos explaining the purpose behind the VIA and case studies with partners.
3.3	Building in-country progress support systems	VIA project managers and service providers established in each country	Dec 2021 and on-going	We have built a new feature into the VIA that allows project partners to consolidate implementation and progress metrics across their schemes. This includes detecting arrays which are not being read or being read but not visualised. It allows the implementer to quickly identify problem areas and troubleshoot.
3.4	Development of self-paced and directed E-Learning on VIA Website	The Water School set up on the VIA site	Half modules complete June 2021 All complete June 2022	The Water School provides in-depth training but keeps faith with the experiential learning ethos of the VIA. Seven15-minute videos have been completed tracking water, salt and nitrate patterns through a year in Richard's garden. These videos have been built into a training platform H5P with annotated and videoed PPT presentations.

Objective 4: *To develop the data analytics that capture the value proposition for each of the five 'customers' of the VIA*

No.	Activity	Output / milestone	Completion date	Comments

4.1	Data analytics for Farmers	Crop level visualisations Report on how farmers want to view data and interact with VIA	June 2020	Currently farmers use the readers tactically i.e. the information is for immediate use: should I irrigate or not? The purpose of the records is to add a strategic dimension to the decision making – what can I learn from last year, or from the farmer with the highest yield. We are exploring opportunities for using WhatsApp to send patterns directly to farmers.
4.2	Data analytics for Scheme management	Crop level visualisation shown spatially Scheme level triads Report on how scheme managers want to view data and interact with VIA	June 2021 and on-going	Crop level triads are useful when the same crop is grown at the same time under similar constraints, so that water remains the dominant variable. The more useful metric appears to be averaging many crop patterns over a full season. This shows whether, on average, schemes are getting wetter or drier. The “average wetness” can also be compared across schemes together with average yields. The “equity” of distribution can be evaluated by looking at the change in variability of wetness.
4.3	Data analytics for Researchers / NGOs	Customised reporting according to specific requirements Report on how researchers and NGOs want to view data and interact with VIA	June 2021 and on-going June 2021 and on-going	We are still building capacity in partners to analyse VIA data. To date, change is happening spontaneously ‘from the bottom’, as farmers respond to new opportunities. We have reports of whole-of-scheme changes, particularly around longer intervals between irrigation events that result in better overall distribution uniformity. There are several reports of schemes getting unused land back into production. In many ways the VIA data system is trying to catch up with what is already happening on the ground.
4.4	Data analytics for Governments	Comparisons of scheme level triads and how they change over time Report on how scheme government agencies want to view data and interact with VIA	June 2021 and on-going	We are experimenting with the level of data aggregation that produces a strong signal that can be acted on by government. For example, we have divided the triad into five regions from very wet to very dry. This allows us to benchmark schemes and quantify change as the number of farmers (crops) in each wetness class (see Water School module 5 for detail). Our MTR reviewers reiterated how important co-design will be with our partners and this aspect requires further work

4.5	Donors	Performance metrics for irrigation investments Report on how donor agencies want to view data and interact with VIA	June 2021 and on-going	Thus far we provide customised reporting to partners on performance metrics. This is largely an M&E function and helps identify bottlenecks in implementation. We have reignited discussions with the World Bank IRIGA project in Mozambique and farmer led project in Uganda, which will help us to distil the metrics required for M&E.

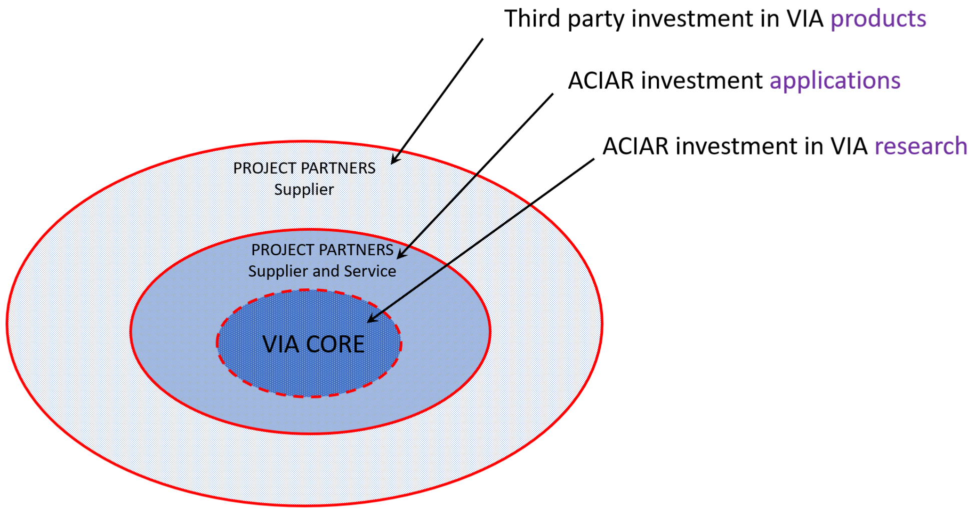
Objective 5: *Create the business models and structures that can deliver the VIA irrigation learning and governance platform*

No.	**Activity**	**Output / milestone**	**Completion date**	**Comments**
5.1	VIA Board	Set up an Interim Board representing the key VIA stakeholders	Monthly meetings from July 2020	The VIA Board comprising Kim Gillis (independent chair), Dan Walker, Michael Robertson, Marna de Lange and Richard Stirzaker was constituted in July 2020 and met at approximately six-week intervals until the company was created. Then a new board took over (Kim Gillis, Simon Dyer, Robyn Johnston, Stuart Thompson).
5.2	IAF grant	Apply for Innovation Accelerator funds	Dec 2020	The IAF grant was successful with funds to support an “Interim CEO” or “Entrepreneur in Residence” and funds to obtain business and legal advice required for setting up the business. Simon Dyer was appointed in March 2021 and has worked full time since. The aim of the IAF grant was to build the case for the CSIRO Major Transactions Committee.
5.3	Business model for MTC	CEO to prepare business model for approval of interim board	Defined business strategy Sept 2021	There was considerable variance between the majority board position on the appropriate business model and what was demanded by CSIRO BD. Eventually a decision was made that the VIA did not need to go through MTC and a not for profit company could be established.
5.4	Business set up	Execute business model approved by MTC	VIA business established	The not-for-profit company was established in May 2022.

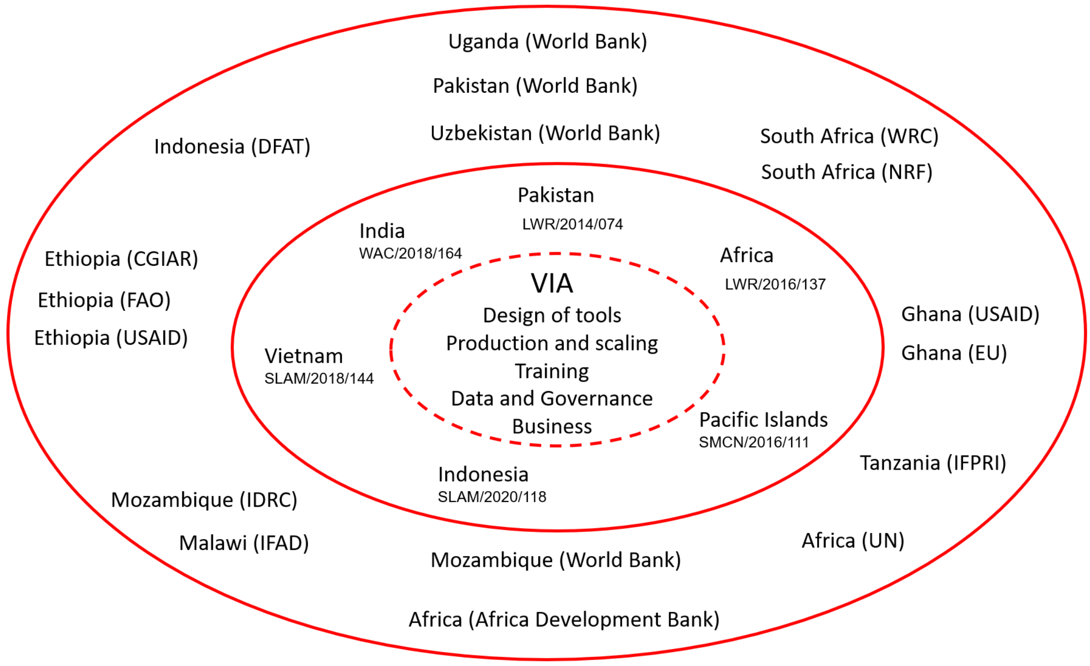
7 Key results and discussion

The project objectives start with sensor designs and development, then production and scaling, then rollout and training, then data system and analytics and finally with a business. The previous section gives brief samples of some of the things the team did. However, it tells us little about whether these activities were successful in achieving the purposes of the VIA.

The five project objectives are interlinked – the sensors, production, training, the data systems and business all have to function for the VIA to work. If any one of them fails, then the VIA fails. To assess the success of the VIA we first look to the response of third parties. ACIAR has been the sole funder of the VIA research – or the VIA core in the centre of the diagram below. ACIAR has also funded the application of the VIA in other projects. There are a growing number of donors investing in the deployment of the VIA around the world.



The diagram below shows the ACIAR projects (middle), the third-party investors and where they are active (outer circle).



The VIA has been funded by ACIAR in two phases over eight years. As the diagrams above show, ACIAR funded six projects to take the VIA and its applications to 12 other countries. A recent google search showed that the following agencies are contributing to the introduction of the VIA around the world: World Bank (Uganda, Pakistan, Mozambique, Uzbekistan); USAID (Ghana, Ethiopia), IFAD (Malawi); FAO (Ethiopia); IDRC (Mozambique); EU (Ghana); IFPRI (Tanzania); WRC (South Africa); CGIAR (Ethiopia), DFAT (Indonesia), Africa Development Bank (Africa) and more. These are uncoordinated and spontaneous responses to the VIA. This donor activity provides independent evidence of the need for VIA-type products and services in the smallholder irrigation sector.

The VIA has no involvement or funding from any of the above initiatives, other than supplying equipment and free data services.

The VIA is not primarily about a new sensor, or even a suite of sensors. It's about how a new way of collecting, displaying and sharing information stimulates social learning and leads to a cascade of benefits. Our Phase 1 reviewer captured it best in his report to ACIAR in 2019.

"Prior to this review, if someone had drawn a crude sketch of factors influencing the livelihoods of small-holder irrigators on a whiteboard and said that the key leverage point was a tool for monitoring soil water, I would have been dubious. I would have questions in the first place whether uncertainty about soil water was the major limit to small holders' livelihoods. Even if convinced that there were substantial benefits from resolving the uncertainty on soil water, I would point to challenges in finding a meaningful representative measure in a field given that small holders are often growing a range of crops, the distribution of water is uneven, and crop establishment and weed infestation are patchy. Nevertheless, a simple measure of soil water at three depths at one point in a plot seems to be a catalyst that unleashes benefits in fields (higher yields, less water, less fertiliser, more weed control) livelihoods (more income, labour available for other activities) and communities (less conflict over water, more time for children's education, spending of extra income, more employment of non-family members, even reports of less thieving in the village). In a way that is truly wonderful, monitoring soil water leads to agency and a sense of control that leads to unpredictable outcomes such as reduced conflict and cooperation on cleaning channels."

For this reason, I have decided to deal with the objectives in reverse order. We are not claiming that a simple sensor led to all the benefits described in this and earlier reports. Once we opened the VIA up to others and made equipment available through the global beta test, many other groups positioned themselves around the VIA. Much of this engagement was good, but not all. By seeking to understand *why* other groups wanted to engage the VIA, and watching *how* they used the VIA, we started to learn what we had in our hands.

Objective 5 contracted us to deliver "Business models", not a Business. The activities under this objective were adjusted twice during two project variations. By the time of the second variation, we realised that if we did not set up a business, then the VIA – and the enormous energy around it - would likely end with the project cycle. Therefore, we changed Objective 5.4 to explicitly setting up a real business.

Whereas the first four objectives were extremely challenging scientifically - and enormous fun - setting up the business was fraught at every level and almost brought down the entire venture. In some ways this is beyond the scope of the review. For this reason, I have documented the story in full in the Appendix. The story must be documented somewhere, because in our view it is by far the weakest link in the R4D chain.

The purpose of ACIAR funding in Objective 5 was to find a way to deliver the VIA to smallholder irrigators in LMICs (low and middle income countries). The problem was not that we wanted to commercialise a product. There are well established pathways for doing that. Our problem was that we wanted to protect the IP so that it would benefit our partners in Africa who helped create it. We needed to create a business from a publicly funded R4D project that was explicitly pro-poor.

ACIAR funded our first commercialisation workshop in May 2014. It was run by consultants “Enterprise Accelerators” with the primary purpose of evaluating whether the Chameleon sensor was a viable product. All workshops described in this section involved representatives of the business development arms of both CSIRO and ACIAR, plus the VIA research team and key external partners. Thus, all parties who were needed to progress decisions on commercial matters were represented in the workshops.

A major decision from this first workshop was not to patent the Chameleon sensor. Advice from our then business partner was that patents were impossible to enforce in this field and made user testing difficult. The only real protection was to establish the product as quickly as possible in the market and build the brand. Speed was everything.

Most research products fail because they do not get robust user testing. As discussed earlier, demand was growing for Chameleon sensors, even though they were still in prototype form. We got permission to set up a beta test, which meant setting up a shop and secure payment system on the CSIRO website. We made sensors in my Canberra lab - but could not keep up with demand.

A long-term goal was to build sensors in Africa, an essential step in reaching our desired price point. In 2016 we set up a small sensor production unit at the University of Pretoria and engaged two young engineering graduates to run it.

In 2017 we entered a contract with a South African company called Rural Integrated Engineering (RIEng) based in Pretoria. Our agreement with RIEng allowed us to build a VIA incubator inside their existing company structure. This gave us the flexibility to build a prototype business, "proto-business", and develop the supply chains into and out of the factory. Our engineering team established in 2016, both in Australia and Africa are the mainstay of the VIA today.

Soon, we were sourcing hundreds of parts from suppliers all over the world and selling 25 different products (including spares) through the on-line shop https://shop.via.farm/. By 2018, we had field data coming in from 280 different locations across 21 countries (our project documentation said we would collect data from 18 locations in two countries). The beta test was overwhelming the project.

Everyone was excited about the success of the beta test, but at the same time agreed that running an international business inside a research organisation was impossible. We were planning a VIA Phase 2 project, which would focus on scaling. A prerequisite for scaling was to have the business entity outside CSIRO. All parties agreed to get this done before the start of the Phase 2 project in June 2019.

To facilitate this, ACIAR contracted the consultants ThinkPlace in May 2018 to do a full 360-degree report into the VIA and its activities. The ThinkPlace final report was delivered in August 2018 and with all parties agreeing there was most definitely a business in the VIA.

In December 2018, CSIRO decided to fund ThinkPlace to do a follow-up consultancy which produced a step-by-step guide and detailed 6-month timeline for establishing a VIA business.

By June 2019, the 6-month deadline had passed with no progress except a decision that the VIA needed to be approved by the CSIRO “Major Transactions Committee” or MTC.

In January 2020, the decision was made that the VIA needed to go through an internal accelerator program called the IAF (Innovation Accelerator Program) and there was no path to MTC without first going through IAF.

The IAF program provided funds for an “Entrepreneur in Residence” to work with the VIA team and refine the business proposition for MTC. Simon Dyer was appointed to this position in Feb 2021.

It was Simon’s job to consult experts in the field to come up with the best business structure for the VIA to reach its stated purpose, and to secure startup funding. The starting point was to find a way to keep the team together that had built the VIA. The production line was both high tech and a ‘high art’, which had taken seven years to perfect.

Simon put forward three options based around a for-profit business linked to a VIA Foundation. This model was recommended from several sources including ThinkPlace, as the best way to retain the business focus of making profit, together with the impact focus through the Foundation.

CSIRO rejected all three options on the basis there may be a perceived conflict of interest of individuals external to CSIRO who were part of the research effort.

Simon had been getting advice that a not-for-profit company (NFP) would – somewhat counterintuitively - be the best business structure for a profitable VIA. This is because many partners had expressed their desire to engage with the VIA as local distributors and/or local manufacturers. It would also keep most of the existing team together because it did not invoke ‘conflict of interest’ for those outside CSIRO. The idea was that the core VIA company would be a relatively small NFP to protect the IP and then facilitate many other for-profit and NFP partners to take the VIA around the world. This fitted a common scenario where funds come through donors who want to engage with local companies.

The not-for-profit model was accepted by CSIRO and the requirement for the business model to pass MTC was dropped.

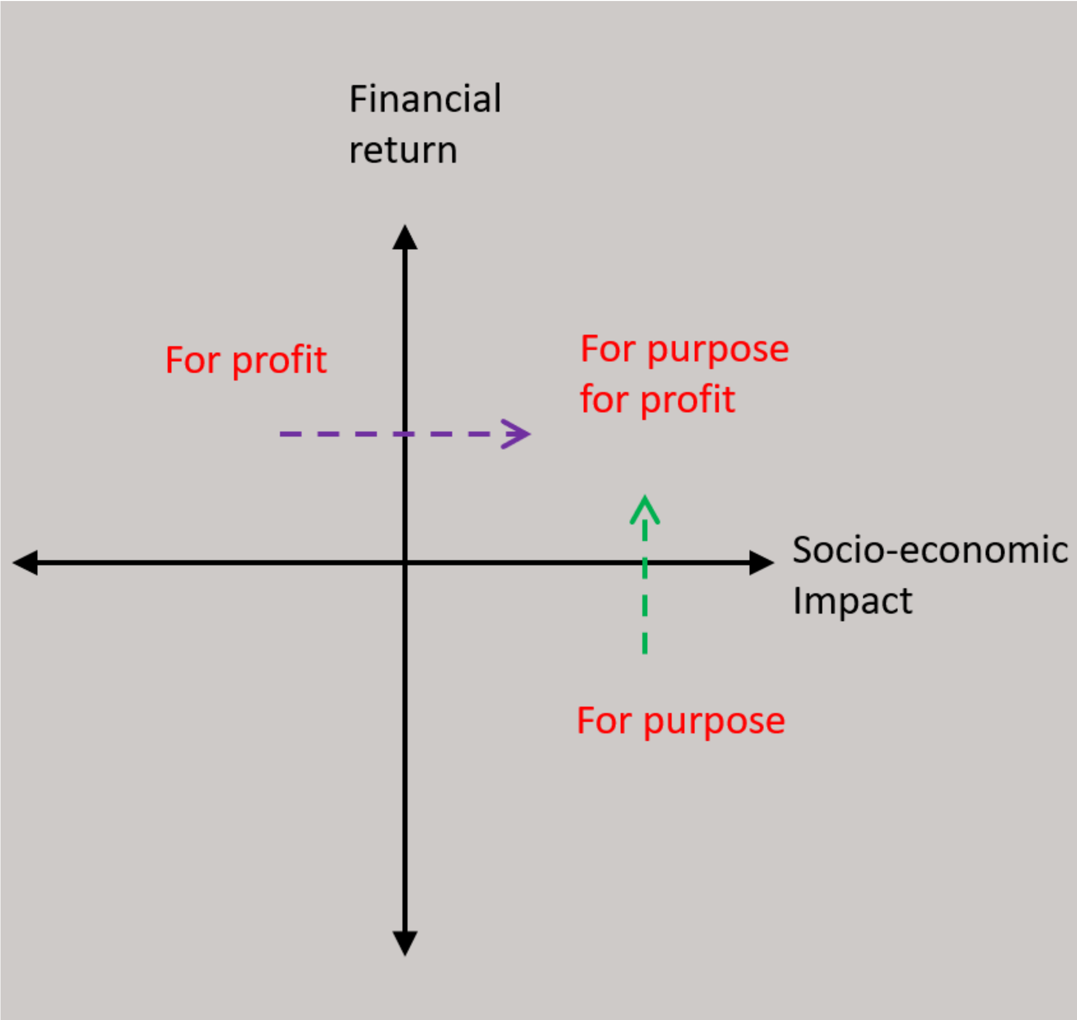
In November 2021, Simon was given in-principle approval to set up the NFP company. All that remained was to determine the conditions of the licence agreement between CSIRO and the VIA NFP company.

CSIRO negotiated a worldwide non-exclusive license agreement for the use of the intellectual property. The financial terms of the agreement were tough for the new start-up, with CSIRO requiring a 10% royalty on gross income from sales to high and most middle-income countries and ownership of all intellectual property created by the VIA and it partners for ten years into the future.

At the time the VIA not-for-profit was set up in May 2022, the VIA beta test had sold $1,576,349 worth of products. These funds had been used to build the factory in Pretoria, employ staff, and to set up the website. The remainder was used as capital for the new Start-up. The VIA now had a fighting chance.

The diagram below tries to make sense of this long journey, in which all parties were working towards the same goal but often at cross purposes. Consider the four quadrants in the diagram depicting a range of options where an entity is primarily profit driven and one that is purpose driven. Goldman Sachs would operate in the top left quadrant and ACIAR in the bottom right. Once the VIA team had been funnelled into the IAF process, the system was designed to set up a VIA entity in the top left quadrant.

This is because IAF had two guiding principles. Most important, the VIA must be set up in a way that maximises short term financial viability (3 years). Second, CSIRO wanted a return on investment. The IAF process posited that the VIA could then navigate the entity from financial stability towards addressing concerns about impact i.e., following the purple arrow.



The VIA team wanted to first protect the purpose - through a company that protected the IP - and then would work towards profitability i.e., following the green arrow. The VIA team believed it had already demonstrated its capability to generate funds through the beta test. Long term financial viability would come through partnerships in the water sector, that these would take time to establish, and the VIA needed to be supported through the transition.

When referring to “CSIRO” and “IAF” above, I describe the decisions of “the system”, not the views of individuals, who in most cases, were searching for a good outcome. Many in CSIRO have championed the VIA, both then and now. Some in the organisation went well above and beyond to ensure the beta test was a success. Our problem was “the system” could not see its internal contradictions because it dealt with the VIA at multiple levels of decision making that were not connected. A for-profit company required cutting out those who held the purpose and the expertise. Why would a venture capitalist looking for a return on investment be concerned about a Malawian irrigator?

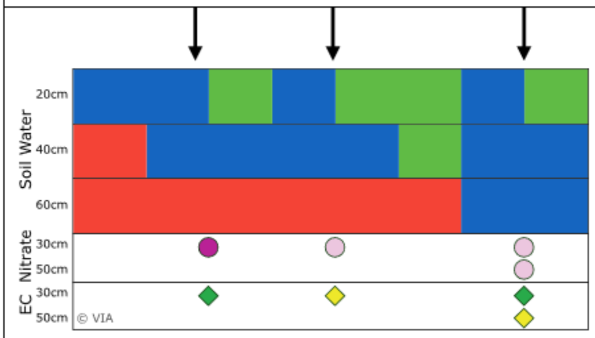
The closest we got to common ground was “why not make a lot of money in rich countries and use it in poor countries?” Those who know the international water sector know that nobody has made money out of soil water monitoring technologies. It would also require us to change the technology to make it fit for high-end irrigators. Given the vast sums of public money invested in the water sector, the path from for-purpose to for-profit must be possible, as long as all parties who helped us get this far can stay engaged.

Which brings us to Objective 4:

Most soil water sensors measure soil water content. Since every soil type is different, the number a sensor provides (how much water is in the soil) is relevant to that particular soil, in that place, with that installation. When data is logged, an irrigator can view the soil water extraction pattern and subjectively decide when to water. In other words, the data is used locally and tactically.

The Chameleon sensor measures soil tension, which gives wet and dry from the perspective of plant stress, independent of the type of soil. Blue means wet and red means dry in any soil. Thus, the information can be acted on by irrigators without any ancillary data.

Our premium product consists of a Chameleon sensor array of three soil water sensors plus a temperature sensor with a unique identifier (ID). The three water sensors are placed in the top, middle and bottom of the rootzone, and the temperature ID sensor placed with the middle sensor. All resistance readings are corrected by this temperature measurement. The array is connected to a portable reader with three LEDs, each of which can turn blue (B), green (G) or red (R). The reader stores the data against the unique ID and transmits through a mobile phone or Wi-Fi access point to the Virtual Irrigation Academy (VIA) website at www.via.farm. When combined with the Wetting Front Detector, salt and nitrate readings can be added to the Chameleon pattern. These patterns reveal wetting and drying, where the roots are active, salt accumulation and nitrate leaching in a simple way.

Water, Nitrate and Salt Pattern	**Meaning**
	The first irrigation event reveals high N and low salt. The second irrigation shows some uptake of N but salt is accumulating. The third irrigation leaches the rootzone at a time when there is no N.

As described in the supplementary material for this review, the above patterns can be aggregated to answer different questions. If the area of each colour is calculated the pattern can be reduced to three numbers – percentage of B, G and R. If this is plotted on a triad diagram, a field or crop can be located in a single position. If many fields are plotted on a triad diagram, the position of the marker shows the wetness and the size of the marker the yield. This data can be displayed over subsequent irrigation seasons to show if schemes are getting wetter or drier and how this impacts the yield. It also allows schemes to be benchmarked against each other.

If the seasonal crop markers are well grouped, then most farmers are managing irrigation in a similar way. If they are spread out, then there are reasons to investigate further. There may be breakdowns in infrastructure or structural inequity in the allocations of water. Sensor arrays are geo-located, so spatial analysis of wetness (or waterlogging / salinity) could identify underlying hydrological issues (the feature has not yet been coded to produce spatial visualisations).

Such applications have generated a lot of interest from Departments of Irrigation. Given it costs well over $10,000 per hectare to establish irrigation land, it would seem appropriate to have a means to track the performance of such investments. In fact, the VIA team have argued that a simple monitoring network should be considered as normal irrigation infrastructure – like pipes and cement. The build-neglect-rebuild syndrome is so entrenched in the smallholder irrigation sector that it would seem appropriate to monitor scheme performance and get early warning before the infrastructure collapses. Certainly, it is more reasonable than expecting poor farmers to invest in water monitoring when the problem has already become serious.

The mid-term review (MTR) team focused on Objective 4, partly because one of the reviewers was an IWMI researcher seconded to the World Bank. The potential of the analytics was acknowledged, but the MTR report advised:

"Activities under objective 4 'Develop the data analytics that capture the value proposition for each of the five 'clients' of the VIA', are mainly driven through an academic approach and insufficiently through a partner co-development lens. Further enhancing the data features at scheme, national and cross-country level aligned with interests from NGOs, governments and donors will require special attention to customer co-design through the remainder of the project."

As discussed earlier, the MTR believed that the best prospect for VIA funding was through large donor projects – and there was some expectation that these products could be co-designed with partners during an 18-month extension. In the absence of the extension the team had to quickly switch tack to the next most likely way of staying financially viable - radically dropping the price of the sensors. This brings us to objectives 1 and 2.

These objectives are difficult to report on in detail, due to their technical nature. There has been continual redesign of all our sensors and readers to move from research products (they work) to developed products (they can be built at scale) to commercial products (they can be built at a price the customer is willing to pay). Most of the changes were driven through feedback from the beta test. Some changes were forced on us, like the global chip shortage during and after COVID. Our decision to try and develop a production line in the poor country of Malawi was another catalyst for innovation.

Early in 2022, the project received an extra $120K to try and build a sensor production line in Malawi, following a direct request from the Malawi Ministry of Agriculture. The VIA had already expanded to over 60 irrigation schemes over the length and breadth of the country. The Ministry proposed a Public-Private-Partnership (PPP). Under this arrangement there could be a guaranteed supply and price of sensors in the country. With that level of certainty, the government could budget the VIA within their donor funded National Irrigation Master Plan. The government could also ensure waivers to certain duties and taxes that had long plagued us when crossing borders.

This idea of local production was not new. We already had a formal request from the Federal Minister for Science and Technology through the Chairman of the Pakistan Council of Research into Water Resources and expressions of interest from India and Vietnam. There were benefits to local production. It would build local expertise and support systems and tap into local networks and funding sources. It would get around the exorbitant costs of freighting finished equipment around the world and the associated duties.

The idea was to select two engineering graduates from Malawi to do internships at the Pretoria production line to learn the ropes and then replicate all the procedures and processes. And this is when we found out that the whole production line had so increased in complexity (juggling the four variables above which are these?) that it was not possible to replicate in a poorly developed country. We had highly skilled engineers in Pretoria, and running the production line had become both high tech and a fine art.

This experience reawakened an old goal – to make an accurate sensor for under $5 that our target audience had a hope of purchasing. Comparable sensors on the market cost tens or hundreds of dollars each – far out of range for a smallholder even if they could interpret the numbers. A three sensor Chameleon array sells today for $75. Three sensors that go with a Chameleon card cost $35 ($12 each). We had been steadily bringing down the cost of production so the selling margin would cover more of the factory costs. But getting the sensors down to $5 was looking impossible.

We spent the past 18 months re-evaluating the components of each version of the sensor we had built since 2015. In parallel we investigated every machine and process in the production line to see how we could speed things up. This would run to hundreds of pages of documentation so cannot be expanded on here. Suffice to say we have created a JV company in Malawi and are today selling sensors in Malawi for approximately $5 each (US$3). It is still not clear whether the Malawi production line can stay viable. But the experience of fine tuning a modular production line represents a major set of scientific breakthroughs and opens a business model for rapid global scaling.

Finally, we get to Objective 3 which links our users, who range from individual farmers purchasing their own equipment to large projects where data can be visualised at multiple scales. Our new website explains each of the tools with a series of professional “How to” videos around how equipment works, how to install and interpret the data. We provide free data services to managers of large projects so that they can track their own implementation performance. The new Water School is a 7 module self-paced experiential learning program for those wanting an in-depth introduction to the VIA. All this is available for review at https://via.farm/ .

Note that little has been mentioned about work in Zimbabwe and Mozambique. The work in these countries was run through the ANU-led TISA project (Transforming Irrigation in sub-Saharan Africa). Both countries had indicated they wanted to scale the VIA and would need support from the VIA team. This was provided through multiple face to face and on-line training meetings. Training included how to keep track of project implementation, troubleshooting and how to repair equipment. The budgets attached to both countries largely related to supply of equipment only.

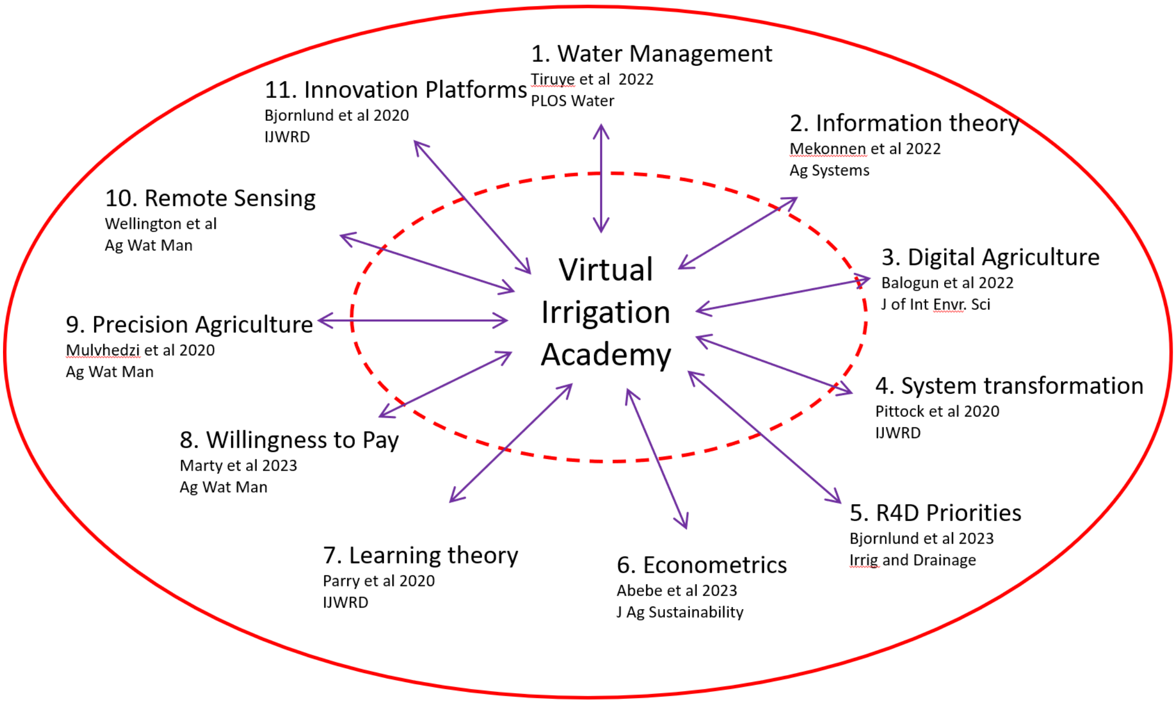
8 Impacts

8.1 Scientific impacts – now and in 5 years

Scientific impacts from the VIA include:

1. A novel sensor that can be mass produced at low cost and retain excellent accuracy
2. A suite of monitoring tools that provide complementary and mutually reinforcing data (water/salt/nitrate)
3. Detecting salinity through chameleon sensors
4. Colour and pattern visualisations that act as boundary objects between different stakeholder knowledge domains
5. The ability to relate yield to patterns
6. The ability to average data across schemes and/or years for M,E&L and benchmarking
7. The ability to show inequality in water distribution across schemes

A wider view of scientific impact is shown below. A quick google search identified 11 scientific disciplines that have shown how the VIA plays into their discipline. In most of the paper below published since 2020, the VIA is a major component. Moreover, this is a list that does not contain a single "VIA author" (or co-author), so it represents an external view of VIA impact in the scientific community. Given the time it takes for publications to work their way through the system, this is likely just the beginning.



8.2 Capacity impacts – now and in 5 years

An example of improving farmer capacity is illustrated from the survey data in the table below. The data were derived from 15 smallholder schemes in Tanzania and Malawi, involving 358 farmers monitoring 736 crops over a period of three years. Farmers were asked to estimate their yields, compared to what they harvested before the introduction of the VIA tools. One quarter of farmers in each country estimated that their yields had increased by more than 50%. However, one quarter of farmers in Tanzania and over a third in Malawi reported that their yields were the same or lower than before. Farmers obtaining lower yields were then asked for the major reason, which included i) running out of water ii) low use of inputs iii) pest and diseases iv) misleading information from the tools. Most farmers reported that low yields were due to running out of water. None of the farmers reported misleading information from the soil water monitoring tools. Overall, farmers estimated that 70% and 63% of their crops had higher yields in Tanzania and Malawi respectively, despite the challenges of inadequate supplies of water, low inputs, pests and diseases.

Country	Irrigation Schemes	Number of Farmers	Crops monitored	Crops surveyed	Change in yield		
					Same or Lower	Increase 0-50%	Increase >50%
Tanzania	8	183	323	271	25	49	26
Malawi	7	175	413	182	35	40	26

Impacts between those with VIA tools and neighbouring farmers has regularly been reported. In a large scheme in Ethiopia, 373 farmers from 36 water user groups reported a 40% increase in water productivity of wheat after using VIA tools. Farmers with equipment were encouraged to share their experience with Water User Groups in a different part of the scheme without the tools, and these famers realised the similar benefits. A study in Tanzania calculated that farmers using Chameleon sensors reduced their water applications by 65% over three years. Their neighbours, who did not have equipment, reduced their irrigation by 47%. Similarly, farmers in Zimbabwe without equipment learned from those who had it installed in their plots and obtained about two thirds of the benefits.

8.3 Community impacts – now and in 5 years

Even though we have been designing ‘farmer-friendly’ tools for a long time, we still thought of this within the confines of ‘irrigation scheduling’ - which means ‘when to turn the water on and when to turn the water off’. This is not how irrigation farmers on smallholder schemes experience the irrigation problem.

When a donor agrees to develop a water resource for rainfed farmers, there is much enthusiasm. Typically, this is expensive work, often around $10,000 per ha. At first, access to water is transformational as farming takes place in the dry season. A village grows up around the new scheme. Later, as more farmers get involved and the conveyance infrastructure ages, there are periodic shortages of water. Farmers with plots closest to the main canals get their water first and others miss out. Soon there are winners and losers. People become opportunistic in their approach to water, grabbing it whenever it becomes available. At almost every scheme, conflict over water ensues.

The story we often hear from farmers in that “we were all scrambling for water - “but with the coming of the sensors, then…”

Irrigators live in the same village next door to other irrigators, from whom they are fighting for water. As soon as they see an opportunity to resolve conflict, they take it. Clearly there is plenty of social capital in these villages to draw on as they make a plan to distribute water equitably. All they need was information they can understand, and information they can share.

8.3.1 Economic impacts

Jona Chikankheni, the VIA country manager in Malawi, carried out an economic analysis of the VIA at plot, scheme and national scales. First, he calculated gross margins for maize and beans (several hundred crops across four schemes) before and after the introduction of the VIA and showed an average increase in gross margin of US$721/ha for maize and US$900/ha for beans. If we were to use these values across the total irrigated area of the whole country, this would be worth around US$60 million per year. This is not a vast amount, both because these are low-value staple crops, and the irrigation industry in Malawi is still small. Nevertheless, if we were to extrapolate this to the 250 million irrigated ha in LMICs, it would be worth US$200 billion annually.

Chikankheni went to the next scale and calculated the value of water at scheme level. This is done by calculating the total revenue from a scheme (from the gross margins) and subtracting the total costs including infrastructure operation and maintenance, land rental, labour and VIA tools. The total revenue minus total costs is then divided by the estimated amount of water used before and after the introduction of the VIA. This rough analysis shows the value of water increased by $0.3 per cubic meter after using the VIA tools. Assuming these farmers saved 30% of the water (for which there is evidence), the value of water available to other farmers would also be around $60 million per year. However, this is a public benefit, not one that those investing in the tools could capture themselves.

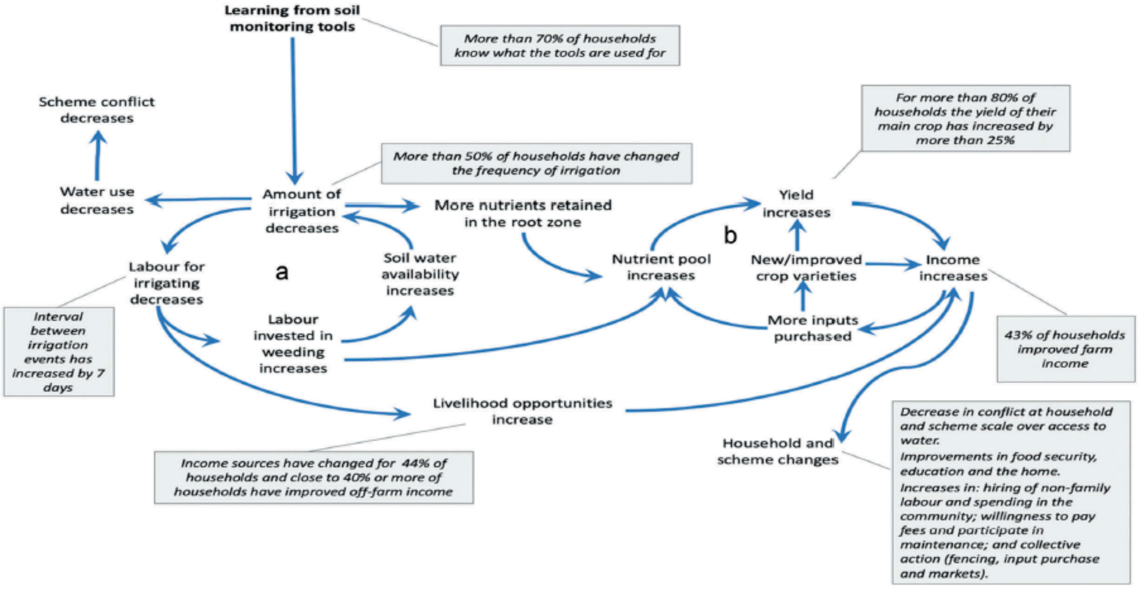
Finally, he calculated the gap between the scheme benefits calculated in the project design stage by donors and those realised after implementation. The Economic Internal rate of Return (EIRR) is calculated from total returns from the scheme divided by the total costs over the economic life of the project. For the scheme under study, he found the donors wildly over-estimated the benefits of irrigation in the design phase, but that the systematic implementation of the VIA could increase the EIRR by 20%. Multiplying that out across the US$2.15 billion Malawi irrigation master plan (IMP), a modest investment in the VIA could generate a windfall to the government of $400 million per year.

These numbers may be a little rubbery, but the point is clear. The benefit to the farmer is significant, but the public benefit of saved water is probably greater. The dividend to governments and donors on irrigation developments would be even greater. It raises all the thorny questions around governance of common pool resources, particularly around who benefits and who pays.

Malawi has a very small (but growing) irrigation industry. The VIA has spread to many countries and anecdotal evidence points to similar outcomes to the above. Calculating the potential value of the VIA globally is a dubious exercise, but the back of the envelope would suggest in the tens to hundreds of billions of dollars per year.

8.3.2 Social impacts

The figure below from Moyo et al (2020) shows a cascading flow of social impacts after the introduction of VIA tools into a scheme in Zimbabwe. These include a decrease in conflict at household and scheme level over water, improvement in education in the household, increase in hire of non-family labour, increased spending in the community, increased willingness to pay water fees and to participate scheme maintenance, and collective action such as fencing, input purchases and marketing.



8.3.3 Environmental impacts

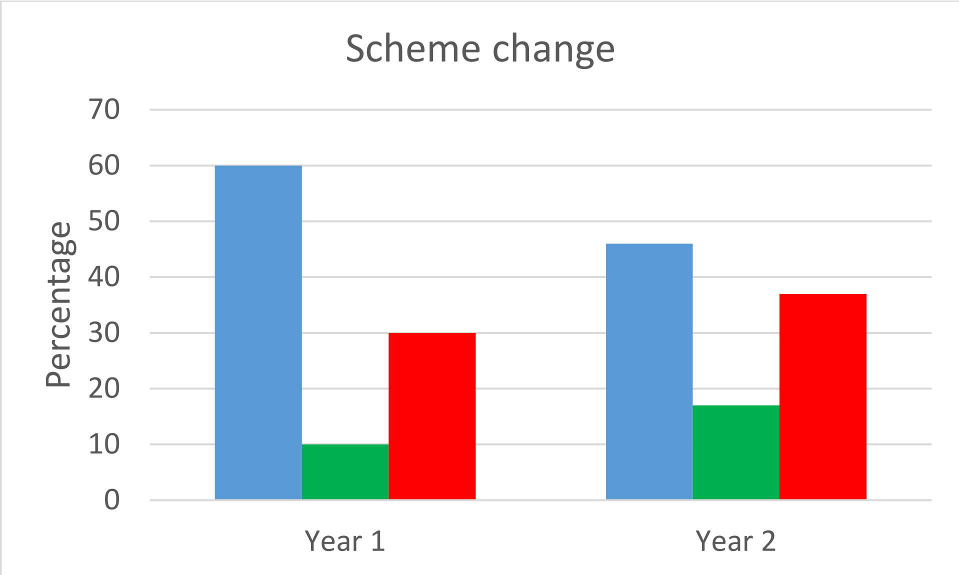
In the survey data below, 90% of irrigators in Tanzania and 71% of irrigators in Malawi reported that they used less water after using VIA tools. This was unexpected, as the general perception at most schemes was that water availability was a problem. Even more unexpected was that 86% of farmers in Tanzania claimed to have reduced their fertiliser rate. They reported applying less fertiliser more often, or fertiliser mixed with manure, having learned about leaching through the Wetting Front Detector. Malawi farmers did not reduce fertiliser use, but fewer farmers were equipped with WFDs, so they had less information.

Country	Chameleon readings	WFD Readings	Reduced water use (%)	Reduced fertiliser use (%)	Reduced conflict (%)
Tanzania	15,556	901	90	86	63
Malawi	9,460	118	71	5	48

Alongside this qualitative self-reporting, the VIA analytics can provide quantitative data of water saved. This is done by integrating the total area of blue, green and red within a crop pattern so the data can be plotted on a triad. Many crops from the same year can be plotted in a triad, to show the distribution of fields that are very wet, wet, moderately wet, moderately dry or dry. This can be repeated in subsequent years and plotted in a histogram.

The VIA is the only data system that can demonstrate environmental performance at scheme scale in a way all parties can easily understand. The figure below gives the changes in the integrated blue, green and red colours after just one year of using VIA products at one scheme in Malawi. There was a 15% reduction in the time that this scheme spent in the blue (wet) zone, which was associated with >50% increase in yield.

More detail can be accessed in Module 5 of the Water School provided in the supplementary material.



8.4 Communication and dissemination activities

The VIA has been widely communicated, partly by us but more broadly through third parties. The question is: what needs to be communicated, by whom and why?

There is much said to proclaim the promising prospects of digital agriculture and its potential to revolutionise R4D in Africa.

The VIA is fully digital, but it tells us something we perhaps don’t want to know - that on ground implementation is the weakest link in R4D projects. A Chameleon Wi-Fi array is ID chipped. When an array is sold, we know about it. When it is installed in a field and claimed on the website, we know about it. Every time it is read, we know about it. And it tells us one thing. We do not invest in effective training of data collection at scale. Papers can be published from small, controlled pilot trials and that remains the metric of choice for claiming impact. The digital nature of the VIA presents a unique accountability system for R4D projects.

The VIA is exploring cost-effective methods of communication that require deeper engagement, learning-by-doing, support and mentoring. Our first product is the VIA Water School - a multimedia on-line training course that we developed in part due to the inability to travel during COVID. The seven-module course is based around experiential learning. Participants need to enrol in the course (free) and their progress is tracked on the VIA system.

The Water School has had over 350 voluntary enrolments and nearly 1500 modules completed. It was piloted in conjunction with the ICID Africa Young Water Professionals network. This started with a Webinar which explained the equipment and philosophy underpinning the VIA and was attended by 158 people from 39 countries. Subsequently 126 completed the VIA Water School over a period of two weeks. During this period, we ran a WhatsApp group to answer queries and to share ideas. A further 118 attended a wrap up Q&A Webinar after the course.

The response from participants was overwhelming and showed us that this sort of training approach filled a large void in the water sector. A few of the many responses are below:

> +263 77 339 7848 ~~Gina
>
> This was indeed an amazing opportunity!It really didn't feel like any other courses because it was engaging and fun, yet in a really effective way. The videos and the explanations were really captivating.learning through practical demonstration with great videos, just like how farmers learn by colors through using the chameleon sensors.It really supports the point that humans understand better by using pictures, colours,drawings and practical demonstration. Well done @Richard Stirzaker, the modules show great planning & thanks @Dr. Mohamed Wahba for facilitating all this, and affording us this opportunity. I hope we continue to collaborate towards a sustainable future of agriculture through irrigation management.
>
> 5:00 am

> +251 97 878 6148 ~Adey
>
> Completed the journey! An amazing journey ever! A journey through knowledge, an in-depth learning, and management of integrated soil-water-plant-food relationships. Integrating science knowledge, ideas, and indigenous practices. I would like to salute Dr. Richard for being great inspiration to many young (and also senior) professionals in the field. 🌱🪴💧🍅🧑‍🌾 Looking forward to the wrapup webinar, where we can have also some room for our questions and answers
>
> 10:58 pm
>
> ❤️👍 5

> I am in love with how the chameleon works and the whole of the VIA classes. I am in need of this technology. This is a great eye opener that will help the agricultural activities in my region and help improve the yields and food security in this region.
>
> This is a game changer. A powerful presentation. Thank you Dr. Wahba and the facilitator for this great opportunity.
>
> #Positive change in agriculture.
>
> Thanks once more 👏. I believe the adoption of this technology will help Africa and other countries improve their agricultural production hence improve food security.
>
> #SDG 2, Zero hunger.
>
> 12:42 am
>
> 👍❤️🙏 6

VIA has an active presence on:

Facebook https://www.facebook.com/virtualirrigationacademy/

Youtube https://www.youtube.com/channel/UCx0OAHX_R709sqkgIk6vkWg

Instagram https://www.instagram.com/virtualirrigationacademy/

Linked in https://www.linkedin.com/company/via-ltd/

9 Conclusions and recommendations

9.1 Conclusions

Nearly 20 years ago I commercialised the Wetting Front Detector (WFD) through an irrigation company called Agriplas. The device was designed specifically for smallholder irrigators and won the International Prize for Water Conservation in Agriculture. To date over 35,000 units have been sold. Many of these were purchased by large scale commercial farmers. Many went into R4D projects. Almost none were purchased by the intended smallholder farmers. At a retail price of $20-30 each, they were far too expensive.

In 2018, USAID commissioned a formal scaling assessment of the WFD. The 'scaling score' of 76% averaged over six different assessment categories slipped the WFD into USAID's second highest class for scaling support "***Very Good:*** *Needs some value chain strengthening or innovation tweaking. Scaling take-off likely to require 5-7 years of donor support.*"

Whereas it is good to have such independent support for scaling, the value proposition for the VIA runs deeper. First, the WFD proved to be far more useful when combined with the new Chameleon sensor. Second, it was the Chameleon that was now the potential game-changer.

Seven years ago, we put out a beta test version of our Chameleon WiFi system, comprising four sensors and a reader, together with a mobile phone friendly logger. At $250 for the system, this was way more expensive than a WFD but proved revolutionary in our project and in many others. We showed – counterintuitively – that most irrigation schemes had more water than everybody thought - that farmers spontaneously cut their water use - and reaped numerous flow-on benefits. Today, well over 50,000 Chameleon sensors have been built (and sold) from our sensor production lines.

On that basis we conclude this project as successful. We also contend that the VIA equipment is making other R4D projects successful.

The first 'willingness-to-pay' studies for VIA equipment are now appearing in the literature. Typically, a third-party donor funds a project to deploy the VIA in a certain country and then the project team finds out what the famers are willing to pay for the things we make. The result is that, while the farmers like the equipment very much, they cannot pay the current retail price. They are poor.

From this we conclude that the VIA is a huge success in R4D projects, and it is likely that a small VIA business could be built up around such projects.

From the many farmers we have spoken to, the price of a single sensor would need to drop to $10 or even $5 each for things to take off outside of projects.

In 2023 we entered an agreement with the company Mechro Ltd to build sensors in Malawi. Today, a single sensor can be purchased in Malawi for $5.

The production cost must be well under $5 for such a retail price. That has been attained. However, a business will not be viable until it is selling in the order of 100,000 sensors per year, and that will take time. The current VIA business was bootstrapped from sales, can produce a maximum of 10,000 sensors per year, and cannot scale.

Experience from the beta test has shown that the VIA needs to be promoted i) through credible partners i.e. those who understand how and why the sensor works and ii) through partners who are networked into the local water sector. We have also found that just engaging with the VIA provides a massive capacity building opportunity for local partners, even before the equipment goes into widespread use.

This means that the investment into the VIA will primarily be about exploring the research and business partnerships that can take a first-to-world product to the bottom of the pyramid, to address what has always been an intractable problem.

The return on investment, both public and private, would be immense for those charged with the responsibility of transforming the irrigation sector in LMICs.

9.2 Recommendations

Recommendation one:

The VIA NFP company needs to explore research and business partnerships that will take the VIA to scale in the many countries it has been piloted. This will provide both the foundation and stimulus for increasing production levels to reach long term financial stability.

Recommendation two:

The VIA products are already being used in new research applications, such as wet/dry rice (Tanzania and others), restoring peatlands (Indonesia) and high value crops in a salt affected delta (Vietnam). Such new applications require adaptations to the equipment to make it fit for purpose.

Recommendation three:

The VIA data analytics provides a unique and untapped potential for governing the water resource. While the base structure for the analytics has been laid down, it needs to be further developed and refined in a new scaling R4D project.

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Ziman, J., 2000, *Real Science: What it is, and what it means*, Cambridge University Press, Cambridge. doi:10.1017/CBO9780511541391

10.2 List of publications produced by project

One of the interesting things about the VIA is that others are publishing far more about it than we are. The following papers have significant focus on the VIA. The next section gives papers with a VIA team member and lastly some Masters theses that focus on the VIA that we are aware of.

No VIA author

Abebe, F., Zuo, A., Ann Wheeler, S., Bjornlund, H., van Rooyen, A., Pittock, J., Mdemu, M. and Chilundo, M., 2020. Irrigators' willingness to pay for the adoption of soil moisture monitoring tools in South-Eastern Africa. *International Journal of Water Resources Development*, *36*(sup1), pp.S246-S267.

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Masters theses

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Sichali, N., 2019. *Improving water and nutrient use efficiency of Maize after flooded rice in Bwanje irrigation scheme, Malawi* (Doctoral dissertation, University of Pretoria).

Kandinga, T.E.H., 2019. *Implications of shallow groundwater dynamics on water and salinity management at Kasinthula Sugarcane Scheme, Malawi* (Doctoral dissertation, University of Pretoria).

11 Appendixes

11.1 Setting up the VIA not-for-profit business