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Final report

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1 Acknowledgements

At the core of the VIA project is "User-led design". That means we put equipment out for testing and feedback as early in the development process as possible. This is a risky way to operate and a fast way to learn. I am thankful that the team has been willing to stay on this journey, however uncomfortable it may be at times.

I'm grateful to our teams on the ground, who have pioneered the VIA with many hundreds of farmers. It's been a steep learning curve and required great perseverance to get through the teething problems. We are amazed at the reaction of the farmers, who responded to the Chameleon colours faster than we ever expected.

This was always a high stakes project, because so many individual parts have to work together, and we were always on new ground. ACIAR has provided us with unwavering support throughout.

2 Executive summary

The Virtual Irrigation Academy (VIA) has developed a suite of tools that show soil water status, nitrate and salt by colours. The colours have meaning, which are linked to action e.g. blue means wet soil and red means dry. We then developed a web-based platform to capture the data from the tools and display them as patterns. Colour and pattern are a universal language, and no specific training is needed to interpret them.

The VIA is built on two premises, which we evaluate in this report:

1. Farmers have local experiential knowledge that is largely untapped (tacit knowledge). If we could provide information in a manner poorly literate farmers could understand and respond to, we could capture this tacit knowledge and the innovation that flows from new understanding.
2. By combining tacit knowledge with scientific (explicit) knowledge, we could document a learning journey and foster a community of social learning around how to improve smallholder irrigated agriculture in Africa.

This project expanded the VIA to over 100 sites in Malawi, Tanzania and South Africa. We have evaluated the benefits of the VIA through interviews, focus groups, on-farm experiments, accreditation surveys and VIA data analytics. The benefits, particularly among smallholder farmers on irrigation schemes, have been far-reaching.

The simple intervention of displaying water and nitrate as colour patterns has opened new opportunities with mutually reinforcing outcomes. In a relatively short space of time, the learning from a minority of farmers dramatically changes mindsets and practices on irrigation schemes. Almost all smallholder farmers reduced their water use. Many get substantially higher yields. Benefits accrue at multiple scales.

The development of our VIA tools is guided by the principle of the Minimum Viable Product (MVP), which enables us to run a continuous beta test program. The MVP allows us to reach our core clients as early as possible in the development process, and to respond to their feedback. Fundamental to this concept is that it is a process of user-led design, so that we find out what our clients want before we try to implement at scale.

Our ultimate goal is to stimulate and nurture social learning around small scale irrigation. We define social learning as knowledge that transcends the boundaries of the project. Learning around water, nutrients and salt becomes embedded in the community and extends beyond the immediate participants and can be sustained beyond the end of the project.

This report is constructed using the Mode 1 / Mode 2 knowledge production systems. Mode 1 is the domain of the expert, looking for universal, or at least transferable knowledge, to pass onto a client. Mode 2 is the domain of the practitioner, is problem centred, with diverse perspectives. Both modes construct and validate knowledge in different ways. The VIA joins them together.

For researchers, irrigation is a science. For farmers - who face site specific constraints and opportunities - irrigation is an art. The VIA connects the science and the art. It is useful for explaining the science to the farmers. But it is even more useful in capturing the innovation of the farmers, interpreting this in the light our scientific understanding and spreading it to others.

3 Background

Around 5% of Africa's cultivated land is equipped for irrigation representing a hardware investment in the range of $90 billion. Some estimates are that Africa could double its area equipped for irrigation in the next 50 years (You et al., 2011). This project is about how we can maximise the return on this investment.

There are almost 600 million farms in the world today, and over 80% of them are less than 2 ha in size (Lowder et al., 2016). Across South and East Asia, Latin America and sub-Saharan Africa, farms less than 5 ha produce 70% of the food calories consumed in these areas and half the food calories produced globally. How much of the global research effort is directed to these people who work at small scale with small budgets?

Supplementing rain with irrigation started with the dawn of agriculture, but it is not clear that any civilisation has managed the longer term implications. Yet the drive to expand the irrigated area continues. What new ideas could help realise the dream of irrigation for Africa?

This report builds on two previous documents namely "The case for a new irrigation research agenda for sub-Saharan Africa" (Stirzaker and Pittock, 2014) and "A soil water and solute learning system for small-scale irrigators in Africa" (Stirzaker et al., 2017).

The Virtual Irrigation Academy is built on two premises, which we evaluate in this report:

1. Farmers have local experiential knowledge that is largely untapped (tacit knowledge). If we could provide information in a manner poorly literate farmers could understand and respond to, we could capture this tacit knowledge and the innovation that flows from new understanding.
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We developed a suite of tools that show soil water status, nitrate and salt by colours. The colours have meaning, which are linked to action e.g. blue means wet soil and red means dry.

We then developed a web-based platform to capture the data from the tools and display them as colour patterns. Colour and pattern are a universal language, and no specific training is needed to interpret them.

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The simple tools in the hands of thousands of farmers create a vast amount of local context-specific information. The VIA platform assembles all information into visualisations that give us robust data around which we can discuss and learn. The combination of spreading wide to maximise our exploration, while retaining the structure of scientific thinking, is what the VIA is all about.

A short history

The first Chameleon sensor was installed in a farmers' field in Tanzania in 2014. This was the part of a much larger ACIAR project called TISA (Transforming Irrigation in sub-Saharan Africa). TISA phase 1 (2013-2017) and phase 2 (2017-2021) investigate the twin interventions of Agricultural Innovation Platforms (markets and institutions) and providing soil water and nutrient information directly to farmers.

The VIA project (2015-2019) was developed to build the core capability to service TISA and other ACIAR projects. By core capability we mean designing, building and supplying large amounts of equipment and creating the data and visualisation platform. The VIA therefore plays a large role in TISA (focus on institutions), an ACIAR project in Pakistan (focus on farmer learning) and an ACIAR project in the South Pacific (focus on water and solute management). Numerous other research groups, individuals and NGO's also use the VIA. In fact the VIA has grown so quickly, that by 2018 we had 1840 sensor arrays sending data back to the VIA platform.

In our project plan we hoped, by the end of the project, to work across 12 schemes in Malawi and Tanzania and to instrument 20 farmer plots per scheme, a total of 24 sites. Yet the VIA is has been deployed - in some form - at well over 200 sites, and continues to grow. This rapid expansion has thrown up many challenges, not least that we are simultaneously running a research program and a business.

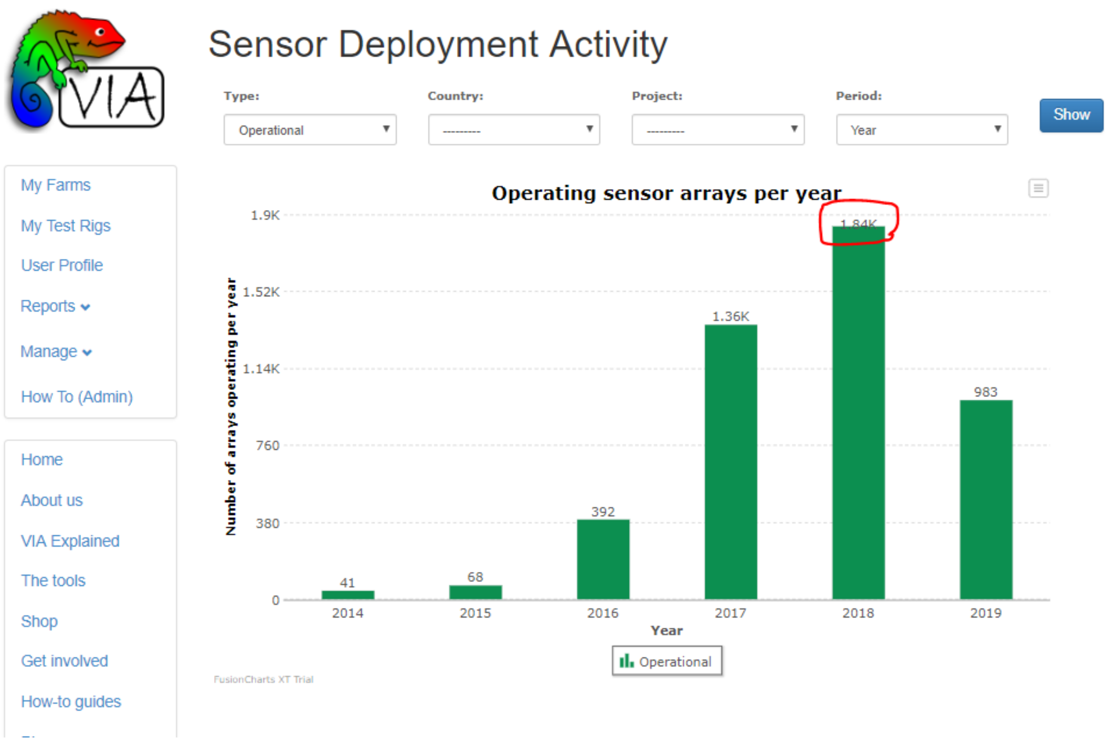


Figure 1. The expansion in the number of Chameleon sensor arrays sending data to the VIA Platform (note that the lower numbers for 2019 is because the main irrigation season in Africa starts in May/June).

4 Objectives

Below are the objectives as we conceived them back in May 2015, as the project proposal documentation was finalised.

1. *To refine and deploy farmer-friendly monitoring tools that measure soil water, nutrients, salt and depth to watertable;*
2. *To develop a "Virtual Irrigation Academy" (VIA) through on-line visualisation of data from the monitoring tools linked to a virtual discussion, learning and teaching space with skilled facilitators;*
3. *To determine how the VIA promotes the social and institutional learning that improves irrigated farm productivity;*
4. *To develop partnerships for the post-project continuation of the VIA and monitoring tools.*

The VIA tools and platform bear little resemblance to what we envisaged just 4 years ago. At that time we were unable to perceive what we now know.

For example, we had no idea what an on-line VIA would look like. In 2014 the production of the Chameleon reader was outsourced to a leading Australian equipment manufacturer. The circuitry was analogue, so all the reader could do was display the coloured lights.

We had three options in mind:

i) The farmer writes down the colours in a book, a project officer enters them into a spreadsheet, the spreadsheet had conditional formatting to display colours and we would post these spreadsheet patterns on a blog.

ii) We would issue farmers with a 'peg board' with different coloured pegs which they would insert after Chameleon readings. These pegs boards would be photographed and displayed on-line.

iii) We would develop phone apps so we could tap colours into a smart phone and visualise the data on smart phones.

Our current VIA is nothing like any of these options. The Chameleon reader is now micro-controller based, we have uniquely identified sensors arrays, a reader that can display data, store data and send to the cloud, a powerful on-line visualisation system for water nitrate and salt, and an increasing ability to do a range of data analytics that demonstrate the learning by farmers, across schemes and over time.

In March 2016, the South African Water Research Commission (WRC) funded the University of Pretoria (UP) to evaluate the Chameleon tool for emerging and large commercial scale farmers in South Africa. The project, entitled "Improving on-farm irrigation water and solute management using simple tools and adaptive learning" started in April 2016 and runs to June 2019, the same end date as the VIA project (approximately AUD 200,000).

The first VIA annual meeting was held at UP in July 2016. The ACIAR program manager held discussions with the WRC and UP project team and ultimately a decision was made to provide "spillover funds" to UP to augment the WRC investment. This was a significant variation increasing the total project value from $2.3 M to almost $3.0 M. Comparing Table 1 (*Tools to be used in the learning system)* in the original proposal (May 15) and the variation (Dec 16) shows how far the project had come in the first 18 months.

The variation was designed to augment the four original objectives above and in addition to:

i) develop a production unit for Chameleon equipment in Africa,
ii) undertake detailed research into the biophysical aspects of the Chameleon tool under controlled conditions at the UP research farm
iii) trial the tools with South African smallholder, 'emerging commercial' and fully commercial farmers
iv) conduct a research program around social and adult learning
v) provide research opportunities for Postgraduate students and
vi) develop UP as training centre for the VIA to serve southern and eastern Africa

A midterm review was carried out by Evan Christen following the second annual meeting and completed in August 2018. The review stated:

"The development of the tools, especially the Chameleon (reader and sensors) has been exceptional. The quality, performance and usability is orders of magnitude higher than the original version whilst maintaining the simplicity the farmers required. This development has not increased cost rather it is probably 30-50% the cost of the original version.

The VIA platform that stores and displays data has a functionality and sophistication much beyond that imagined at the start of the project. The depth of use to which it can be put is only starting to be realised, from individual farmers, to water agencies to irrigation designers. The benefits of the platform need to be better communicated to the partners."

The review made 18 recommendations to CSIRO and 6 to ACIAR which were subsequently negotiated at length. Two issues came into sharp focus. The first was that Objective 3 (Social and institutional learning) was lagging behind because key staff assigned to this objective from ASARECA resigned soon after the project began. A widely circulated advertisement for a replacement drew no suitable candidates. Second, the demand for the VIA tools and services was growing fast and we could not keep up with the demand. The decision was made to reduce the effort going into the social / adult learning and to move these resources to scaling our ability to produce high quality equipment. This was documented in a letter from ACIAR to CSIRO in September 2017.

"Following feedback from the PL Dr Richard Stirzaker to the ACIAR MTR and discussion between him and Evan Christen the RPM, it was decided on 13/9/2017 that there needs to be some adjustment to the project. This adjustment is required to overcome the reality of the time constraints of the project leader, the overall resource constraints of the project and the findings of the first two years regarding the adult learning research.

The point of this adjustment is that the project needs to focus its effort more on delivering the production line for the tools (Chameleon) and the commercialisation of this production line in the private sector to ensure a sustainable post project availability of the tools, and the delivery of the web based data management/learning system. The first two years of the project demonstrate that achieving this will require more time of the project leader and resources than originally anticipated.

In order to focus on this the project needs to reduce effort elsewhere. It was agreed that effort will be reduced in objective 3 activities see Table 1 and 2 below."

5 Methodology

The development of the VIA portfolio of research is 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.

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.

Table 1. Some difference between Mode 1 and Mode 2 research

	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

The VIA is built around the Chameleon soil water sensor. We needed to create a new sensor that was inexpensive, sufficiently accurate, did not need calibration, was not difficult to install and was easy to interpret.

Our first choice was measuring soil water tension over soil water content because tension has the same meaning for the irrigator, regardless of soil type. Second, tension based sensors equilibrate with the soil and then measure 'themselves'. As long as there is reasonable soil contact, installation does not need to be precise, as they are not sensitive to soil disturbance. We had to have a robust sensor that could be used in low skill situations.

We then chose the resistivity method of measurement because the electronics are fairly straight forward. This method measures change in resistance as a porous medium between two electrodes absorbs and desorbs soil moisture. This is the same method as the gypsum block, except that gypsum has very small pores that do not start to desorb until around 50 kPa, a tension at which most horticultural crops are already experiencing water stress. For that reason, gypsum blocks have largely gone out of favour with irrigators.

We redesigned the sensor multiple times, eventually using embossed nickel immersion gold (ENIG) electrodes mounted in a 3 D printed cradle. Every part of the design and redesign process was done to reduce cost and build time with the minimum acceptable impact on accuracy and robustness. We have now built over 1000 Chameleon readers and 20,000 Chameleon sensors.

The development of our VIA tools is guided by the principle of the Minimum Viable Product (MVP), which enables us to run a continuous beta test program. The MVP allows us to reach our core clients as early as possible in the development process, and to respond to their feedback. Fundamental to this concept is that it is a process of user-led design, so that we find out what our clients want before we try to implement at scale.

In our original business model, we hoped to make the monitoring equipment so cheap we could scale from the bottom up through farmer purchases, in the same way as a farmer may purchase crop inputs like fertiliser or seed. Although our equipment is less expensive than anything else on the market, going for 'cheap' is not a good strategy in the early stages. It does not help us to improve the quality and robustness of the tools, nor does it help us to build the farmer support systems. We have since engaged in a dual strategy of i) developing the VIA towards an information system that could generate funds to subsidise equipment and services to farmers and ii) developing the lowest cost embodiment of the technology for maximum farmer adoption (the Chameleon Card see https://via.farm/the-tools/)

Our principal partners in Malawi include the Department of Agricultural Research Services (DARS) and the Department of Irrigation, who carried out all the installation and monitoring on the irrigation schemes. Research projects were also conducted by the Lilongwe University for Agriculture and Natural Resources (LUANAR) and DARS. Our lead partner in Tanzania was the National Irrigation Research Commission, with day to day work carried out by the Arusha Technical College. Research in South Africa was carried out with the University of Pretoria.

Two private sector partners have played a central role in the VIA. Solutech in Canberra has developed and manages the VIA platform and RIEng in Pretoria runs the Chameleon production line.

Our work with smallholder farmers follows the principle of knowledge co-creation (Nonaka et al., 1995). 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. We call this 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 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.

We follow the principles of adaptive management, which 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 (Holling, 1978; Lee, 1993; Walters, 1986). Adaptive management 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.

We explore different theories of learning, such as Double-loop learning, which attempts to break out of the accepted frameworks by challenging the 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. One example described in this report 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.

Our ultimate goal is to stimulate and nurture social learning around small scale irrigation. We define social learning as knowledge that transcends the boundaries of the project. Learning around water, nutrients and salt becomes embedded in the community and extends beyond the immediate participants and can be sustained beyond the end of the project.

The overall VIA methodology is perhaps best explained in Figure 2, where we distinguish 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.

Mode 2 is very different. 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. The VIA platform connects both these worlds (modes). Farmers and researchers share the patterns on the VIA, which then allows for a structured learning process.

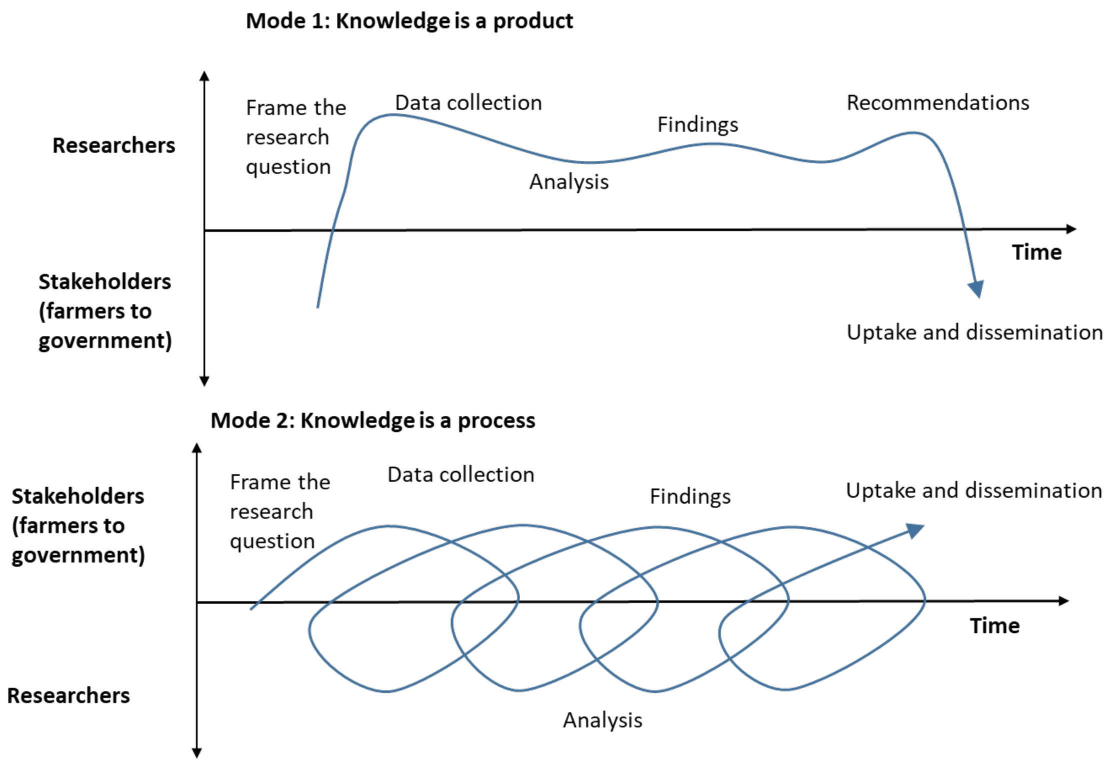


Figure 2. The difference between knowledge as a product and knowledge as a process (from Ison et al 2011).

6 Achievements against activities and outputs/milestones

Objective 1: To refine and deploy farmer-friendly monitoring tools that measure soil water, nutrients, salt and depth to watertable;

1.1 Select schemes and learning communities

The original aim of the project was to select three irrigation schemes in the first year and train the national staff how to run the VIA. This involved explaining how the different tools work, how to configure the VIA platform and how to do basic troubleshooting in the field. Then, when expertise had been built up, the aim was to expand by adding 3 new schemes each year, whilst keeping the original schemes going.

Irrigation schemes are built with public and donor funds and generally include 50 to 200 farmers using shared infrastructure, managed by a local irrigation management committee. Typically the plot size in Tanzania was 0.5 to 1 ha, but in Malawi they can be very small, often less than 0.2 ha per farmer. The aim was to select around 20 farmers per scheme, based on gender and position in the scheme, as some locations are more advantageous than others (head and tail end of schemes). Each selected farmer was given a Chameleon sensor array, and some were provided with FullStop Wetting Front Detectors (WFD). The Chameleon reader was generally kept either a ‘data collector’ employed by the project or the local irrigation officer.

The main irrigation season is from April to November. We missed the first irrigation season due to the delays in getting all the contracts and equipment distributed. The Malawi team successfully engaged three schemes each in 2016, 2017, and 2018, directly involving 175 farmers and monitoring 264 crops. Malawi also operated at 7 research sites, including the Lilongwe University of Agricultural and Natural Resources and the Kasinthula Research Station. Three Masters students, based at the University of Pretoria, carried out their field research on farmer schemes in Malawi.

The number of Chameleon readings taken per scheme is important, as these are done manually by the farmer or extension worker and the frequency of data collection tells us something about the demand for information. Full details are provided in a separate document. The Malawian team chose to focus the use of WFDs at the research sites, so they could gain experience in taking and interpreting nitrate and salt data before extending to farmers.

Table 2. The Irrigation Schemes for Malawi

Irrigation Schemes	Started Monitoring	Number of Farmers	Crop monitored	Chameleon readings	WFD readings
Bwanje Irrigation scheme	May 2016	29	49	1135	0
Nanzolo Irrigation Scheme	May 2016	27	55	1339	8
Kasinthula cane growers	Jun 2016	21	29	777	19

Irrigation Schemes	**Started Monitoring**	**Number of Farmers**	**Crop monitored**	**Chameleon readings**	**WFD readings**
Mthumba Irrigation Scheme	May 2017	22	26	1605	28
Tadala Irrigation Scheme	Jun 2017	25	42	1947	7
Matabwa Irrigation Scheme	Aug 2017	25	36	576	1
Mpitilira Irrigation scheme	Apr 2018	6	6	164	0
Mwalija Solar Powered Irrigation Scheme	May 2018	6	6	872	19
Tiphunzire Irrigation scheme	July 18	14	15	283	0
Total		**175**	**264**	**8698**	**82**
Research Projects			Crop monitored	Chameleon readings	WFD readings
Kasinthula research station	May 2017		69	3850	87
Sichali (Masters student)	Aug 2017		24	651	18
Chinula (Masters student)	Aug 2017		24	675	24
Kadinga (Masters student)	Aug 2017		20	206	176
Lilongwe University	Sep 2017		12	3451	63
Kasinthula research drip site	Mar 2018		6	807	14
Chisanja (Private sector)	Jul 2018		4	129	0
Total			**159**	**9769**	**382**

The Tanzanian team operated at two schemes in 2016, added two more in 2017 and five more in 2018. They directly involved 183 farmers and monitored 262 crops. There was less formal research in Tanzania (only Arusha Technical College), but a lot of informal research, particularly relating to wet/dry rice.

Table 3. The Irrigation Schemes for Tanzania

Irrigation Schemes	**Started Monitoring**	**Number of Farmers**	**Crop monitored**	**Chameleon readings**	**WFD readings**
Chinangali Irrigation Scheme	Jun 2016	19	42	4436	0
Kiwere Irrigation Scheme (VIA)	Aug 2016	21	49	1932	105

Irrigation Schemes	Started Monitoring	Number of Farmers	Crop monitored	Chameleon readings	WFD readings
Buigiri Irrigation Scheme	Sep 2017	19	23	3793	156
Msolwa Irrigation Scheme	Mar 2017	34	57	4020	640
Luganga Irrigation Scheme	Jun 2018	21	22	652	0
Mangalali Irrigation scheme	Jun 2018	21	21	934	0
Njage Irrigation Scheme	Jun 2018	14	14	545	0
Mkula Irrigation Scheme	Aug 2018	21	21	1530	0
Fufu irrigation Scheme	Sep 2018	13	13	811	0
Total		**183**	**262**	**18653**	**901**
Research Projects	Aug 2016		Crop monitored	Chameleon readings	WFD readings
Arusha Technical College			8	809	0
Total			**159**	**9769**	**382**

1.2 Training in the use of tools and instrumentation of farms

Training in the VIA is an on-going challenge. At first we ran some full-day classroom training sessions for our country teams, to explain how the equipment works, basic interpretation, installation and troubleshooting. We also had to explain how to configure sites on the VIA and create the visualisations. We quickly learned that training large groups was a poor use of our resources, and we needed to train fewer people to a high standard. Moreover, the VIA platform was changing all the time, and it was hard to keep up to date. Now we have appointed VIA Country Managers in each country who are continuously mentored with a weekly Skype call so that training is more or less continuous.

Training farmers on the other hand, was easy. They found the tools intuitive. We never told them what Chameleon, nitrate or salt colours they *ought* to get. We told them what the colours mean, and that they should not change their current practice unless they were sure they could trust the tools. The changes farmers made were more dramatic than we could have expected, to the point of scaring us. As we expand, farmer to farmer training is by far the most effective method.

There is also a considerable training component within the wider research team across all four countries. In particular we have tried to help scientists to make the Mode 1 to Mode 2 transition. This has had mixed success amongst some senior scientists, and is extremely challenging to younger scientists (and also extremely rewarding).

Our aim is to build up training resources on the VIA platform itself. This includes instructions around using the tools, uploading data, troubleshooting and FAQs. We hope in the future to create online training and accreditation courses.

1.3 Research on farmer-driven questions

The project had seven Masters students working on various issues. Topics i-iv below are genuine problems first experienced on the schemes. For example, Kasinthula sugar had a large area of salinity that was suppressing yields. This was a very local phenomenon where water tables changes were sensitive to local changes in management. The student investigated 'floating flags' in wells to alert farmers to changing water table levels.

The work on Bwanje irrigation scheme by Chinula and Sichali growing beans and maize after flooded rice will have far-reaching consequences. The research showed that both crops extracted water from below 1 m depth and could be successfully grown in the dry season with just two irrigations. Hundreds of ha of irrigated land that was abandoned in the dry season could now be cultivated.

Research topics v-vii below are largely questions posed by scientists, not farmers. Two-page summaries of each of these projects are provided in a separate document.

Theses i-iii have been submitted and passed examination. The remainder are in final write up stage.

i. Implications of shallow groundwater dynamics on water and salinity management at Kasinthula Sugarcane Irrigation Scheme, Malawi. (Trencio Kandinga)
ii. Improving Water and Nutrient Use Efficiency of Maize After Flooded Rice in Bwanje Valley Irrigation Scheme (Nicholas Sichali)
iii. Improving Water and Nutrient Use Efficiency of Phaseolus Vulgaris After Flooded Rice in Bwanje Valley Irrigation Scheme, Malawi (Thandiwe Chinula)
iv. Factors Affecting Farmer's Irrigation Management Decisions in the Taung Region of North West Province (Nokuluga Mente)
v. Water Stress Response of Pecans (*Carya Illinoinensis* Wangenh.C.Koch) at different phenological stages. (Aubrey Motshweneng)
vi. Irrigation scheduling of potatoes using chameleons water sensors with different switch point sensitivities (Karabo Deane)
vii. Improving Water and Nitrogen Use Efficiency of Green Maize Using Simple Tools And The Soil Water Balance Model (Pati Thakali)

1.4 Refinement of monitoring tools

A summary of refinement of the tools would run to tens of pages. Here, just the briefest overview is given.

We have hundreds of VIA users, many who bought equipment from our on-line shop and expect a perfect product. Our user base provides enormous feedback. Many problems are straight forward, like finding plugs where the wires hold fast under rough treatment in the field. Nine problems out of ten are due to loose wires. Or users in Africa wanted the charging point on a Chameleon reader to match their most common plug – the Android phone. Such problems just required substitution of one part for another.

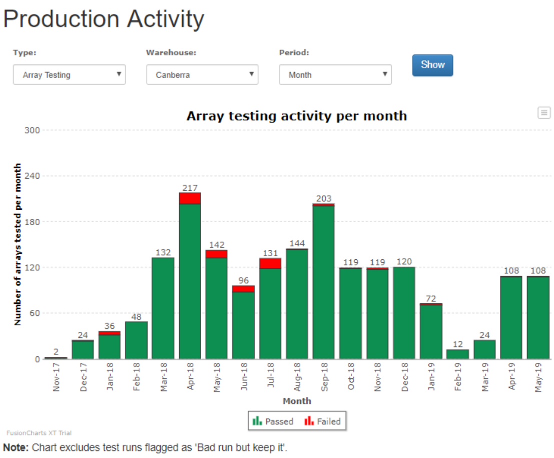
Many changes have required major reengineering. For example, the Chameleon reader initially required the person taking the reader to have a Smartphone, so the data could be sent to the cloud via the Hotspot. But farmers without phones wanted control of the readers themselves, so they could make readings when they needed the information. Thus we built a storage capacity into the reader. Farmers can share the reader around during the week and then give it to an extension worker to upload all the data.

The sensors are constantly being adjusted to improve performance, and the ease and cost of manufacture. We run five 3D printers full time, constantly making minor changes to the design. We run eleven Wi-Fi based sensor testing rigs across Canberra and Pretoria with half-hour uploads 24/7, with 396 sensors under evaluation at any one time.

Every single sensor is individually tested, and it probably costs us as much to test sensors as to build them. This is both for quality control and to fine-tune our production systems. Quality control is essential, not just for reputation but because giving farmers wrong information could be catastrophic.

Figure 3 shows sensor testing results from our Canberra (left) and Pretoria (right) production lines. We normally test 150 to 250 sensors per week on each production line. The green shows sensors that passed and the red sensors that failed. The failure rate at the research production line is now very low, but we still have considerable problems in Pretoria, where one-third of sensors fail. This adds considerably to our costs.

Canberra is essentially a research production line where rigorous testing and constant adjustments has led to steady improvement in speed of production and quality. The problems in Pretoria show how difficult it is to make these sensors. They might be simple and inexpensive, but there is no room for error in their fabrication.



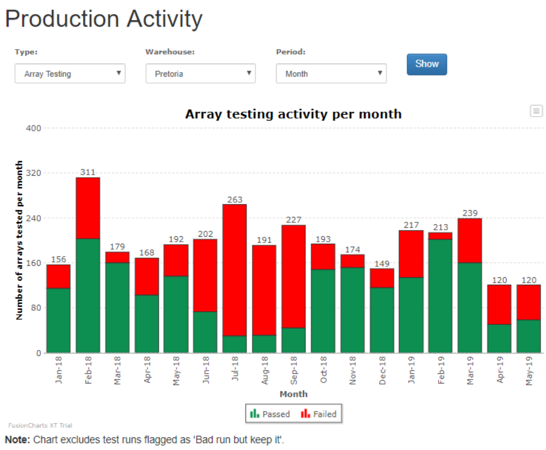


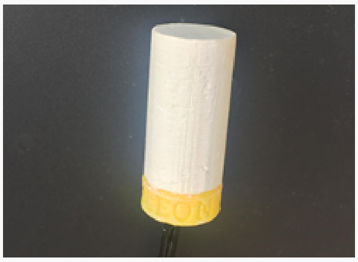
Figure 3. Sensor production at our Canberra (left) and Pretoria (right) production lines, with green showing 'passed' and red showing 'failed' sensors.

1.5 Financial analysis of cost and benefits of tool use to farmers

For various reasons, the cost of VIA equipment is different in the Australian and South African online shops (our teams are supplied at South African prices). In South Africa, the Chameleon Sensor Arrays (3 sensors plus one temp ID on a plug) are listed at $60, the Reader at $150, the WFD at $48 (for 2 detectors in a box), The Chameleon EC meter at $40, nitrate test strips at $52 and Chameleon Card plus 3 sensors at $99.

These prices are very low compared to anything else on the market. Yet they are very high for a small scale farmer. Our pricing policy has caused considerable angst. On the one hand, making the products available for sale is essential for our beta test program, where we want to attract a variety of different users and explore potential markets. On the other, these prices are fairly trivial for research or development projects. We thus find ourselves expending large resources servicing other projects and providing a lot of ‘free’ service and advice.

In terms of cost-benefit to farmers, this is described in the Impacts section.



Chameleon Soil Water Sensor

The Chameleon Soil Water Sensor measures how hard it is for plants to suck water out of the soil and the data is displayed as coloured lights.

More Info

Chameleon Card

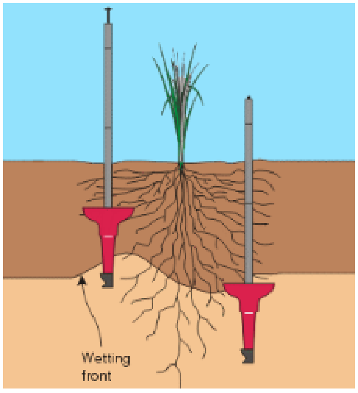
The Chameleon Card allows manual reading of single Chameleon Soil Water Sensors and shows soil water as blue, green or red on a single LED.

More Info

Chameleon Wi-Fi Reader

The Wi-Fi Reader measures a sensor array comprised of three Chameleon Soil Water Sensors and a temperature plus ID sensor. The Chameleon Reader can be used to read any number of sensor arrays, can log data and upload data to the VIA platform.

More Info



FullStop Wetting Front Detector

The FullStop Wetting Front Detector tells you how deep water moves into the soil during and shortly after irrigation. It also captures a soil water solution sample which can be extracted using a syringe.

More Info

Measuring Nutrients - Nitrate Test Strips

Nitrate test strips are used to indicate the amount of nitrate moving in the root zone. Nitrate (the main form of soluble nitrogen in soils) moves with water and is easily leached from the soil by over-irrigation.

More Info

Measuring Salt - Chameleon EC meter

EC meters measure electrical conductivity and are used to show whether salt is building up in the root-zone (under irrigation) or being continually flushed out (over-irrigation).

More Info

Objective 2: To develop a "Virtual Irrigation Academy" (VIA) through on-line visualisation of data from the monitoring tools linked to a virtual discussion, learning and teaching space with skilled facilitators;

2.1 Scope out Visualisation, database, data transfer, mobility and communication requirements

2.2 Software development

2.3 On-going refinement of VIA platforms

Objective 2 cannot easily be described in words. The VIA website is open to the public at https://via.farm/. Many of the features of the VIA are illustrated in the following pages. However, the different levels of the VIA require specific password protected permission.

For development purposes, the VIA platform exists in three 'forms'. There is a development site where all new code is compiled. There is a UAT site (User Acceptance Testing) where all modifications are rigorously tested. This is essential for a complex site where introducing new features can easily 'break' the existing ones. After UAT testing all changes are moved to the live site at https://via.farm/. This means that the platform can be continually improved without interrupting the VIA Users.

The platform is upgraded on a regular basis, in response to the research team and users, for example making the Reader easier to connect to a smartphone and creating more intuitive visualisations. The VIA is increasingly used to provide metrics on the production line, sensor testing and performance in the field.

Objective 3: To determine how the VIA promotes the social and institutional learning that improves irrigated farm productivity;

3.1 Understanding the learning journeys

3.2 Mentoring of learning community

3.3 Documenting changes in farm and scheme productivity and incomes

3.4 Three training courses run each year/country

3.5 Research of learning outcomes

As discussed in the Objectives section, it was decided following the mid-term review to reduce out time input into this aspect of the work, and focus on the Chameleon production line. However, a considerable amount of work has been done re-training and mentoring and trying to track learning though VIA analytics.

We also 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. The SenseMaker approach offers a methodological breakthrough for recognising patterns and trends in perceptions, behaviours and relationships that are not captured in traditional survey techniques.

This objective was led by UP and ATC (Tanzania), two partners who are not part of the VIA Phase 2 project. Both partners have been given a 6 month extension to write up the work under this objective.

Objective 4: To develop partnerships for the post-project continuation of the VIA and monitoring tools.

4.1 Engagement of partners in the VIA.

4.2 Prototype to commercial Chameleon

4.3 Developing private sector linkages

The VIA is led by CSIRO in Canberra where most of the basic research is carried out, including the design and testing of the equipment and the research production line facility. A Canberra based company, Solutech, leads the electronics and database component of the work and the VIA online platform. A second private sector partner in South Africa, Rural Integrated Engineering (RIEng) runs our Chameleon production line and quality control processes. RIEng also manages the distribution of all monitoring equipment to partners in Africa. Our implementation partners in Africa are primarily drawn from the government agencies. We have been in constant dialogue other research projects and NGOs to ascertain their needs and how they want to interact with the VIA in the future.

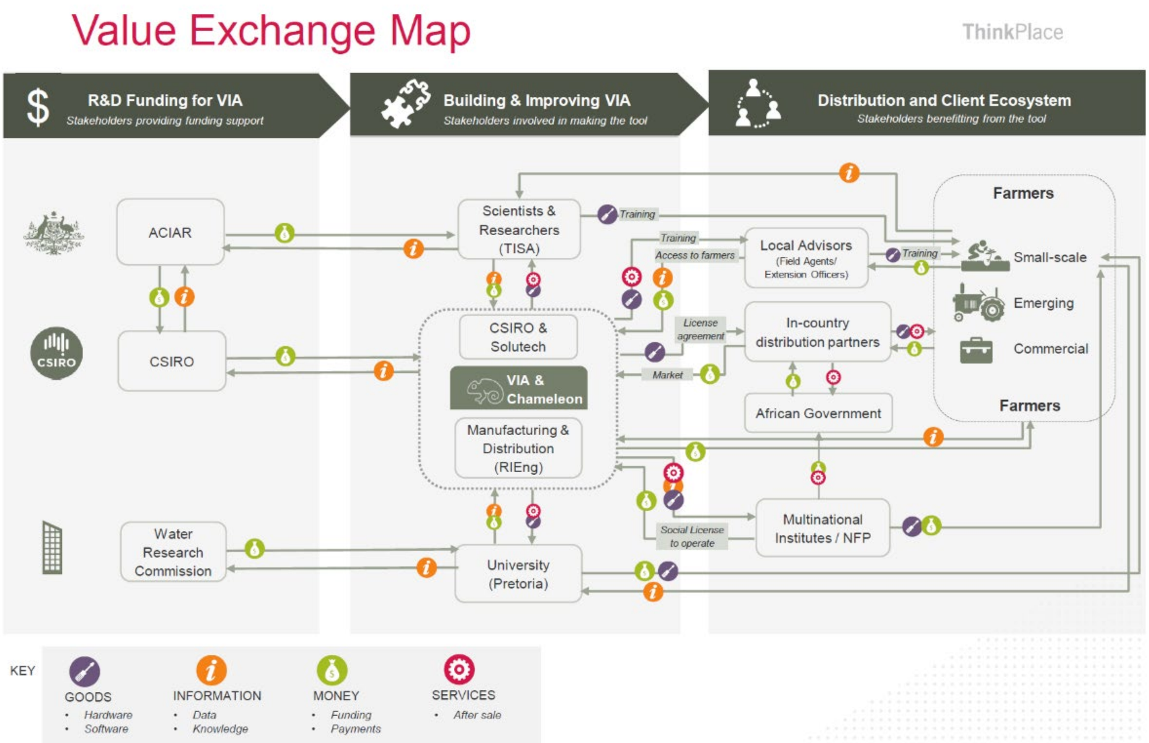


Figure 4. The VIA partnerships

Objective 5: Additional activities from the South African component

5.1 Developing a production unit for Chameleon equipment in Africa

5.2 Research into the biophysical aspects of the VIA across a spectrum of commercial and small scale farmers

5.3 Research into adult learning

5.4 Setting up the UP Hatfield farm as a research and demonstration site and a training centre

5.5 Capacity building for VIA participants from various countries by sharing experiences and further training

This objective is fully covered in the report "Improving on-farm irrigation water and solute management using simple tools and adaptive learning" (176 pages).

Briefly, engagement with South Africa started with the project variation in 2017. The focus here was on emerging farmers, a very important sector in the South Africa political economy who farm up to 50 ha. Many of these farmers are essentially out-growers for large companies including sugar, citrus and barley (beer). We also worked with large scale commercial farmers, many of whom have approached the VIA. One of the aims was to evaluate how simple equipment impacted different classes of farmers, from those who had never monitored water before (Malawi / Tanzania) through to large scale farmers who had already invested in irrigation scheduling tools.

As shown in Table 4, we are working at a large number of sites in South Africa, covering emerging farmers, large scale commercial farmers and research sites. This allows us to compare the benefits of the VIA to farmers operating across a range of skill levels.

Table 4. Number of VIA sites in South Africa

Engagement	Number of sites
Emerging farmers	28
Large scale commercial	27
NGO	9
Research	20
Total	84

A major part of our South Africa engagement has been to build a local African based supply chain. This is not easy. The components required to build Chameleon sensors and readers are sourced from many different companies. Also the grades of sensing material and gypsum vary from supplier to supplier and batch to batch. We have carried many hundreds of kg of materials (literally) through African airports. As you see clearly in Figure 3, we still have large sensor failure rates in Pretoria, which is often due to substituting apparently matching materials into the production line.

We have also had challenges freighting equipment into African countries, especially with exorbitant taxes and charges. Despite these issues, the total number of our production version of the sensor will soon reach 20,000, in addition to the many prototype sensors that were distributed prior to Feb 2017 (Figure 5). We have put thousands of sensors in the ground.

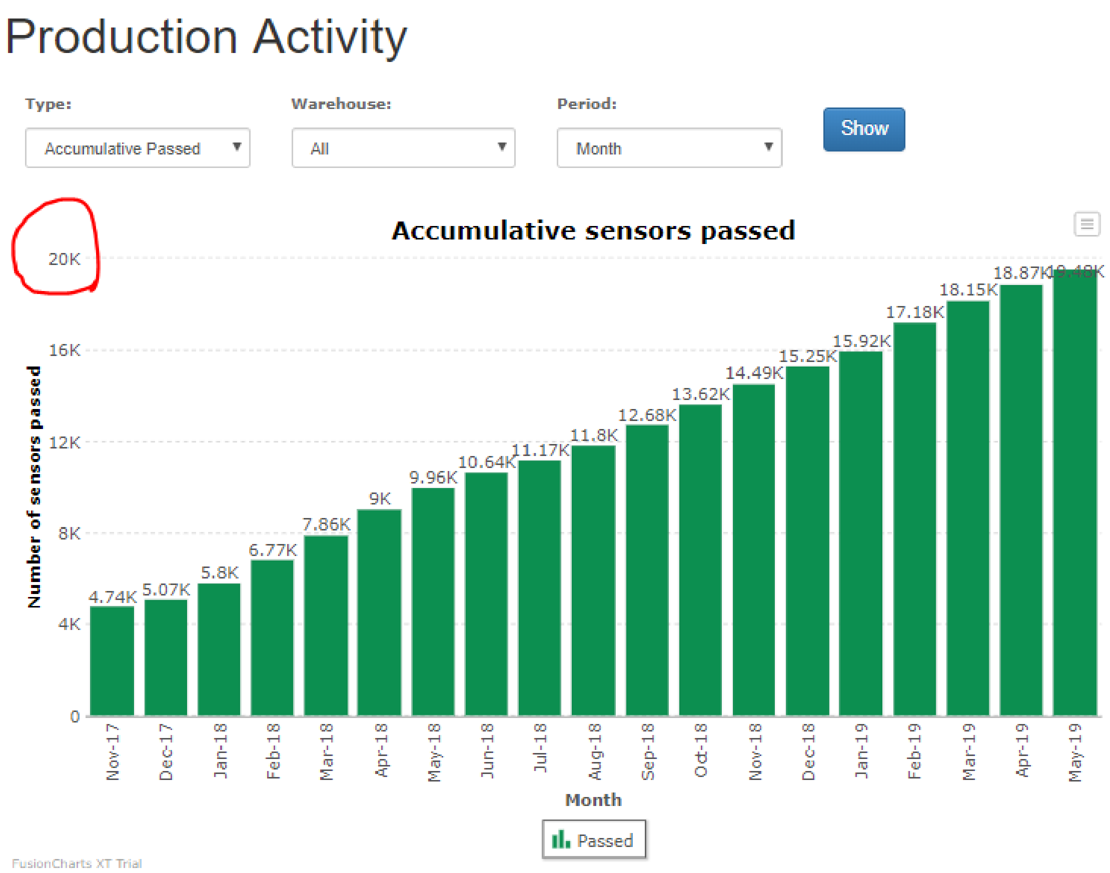


Figure 5. Total number of the commercial grade sensors built and passed QC in Canberra and Pretoria since Feb 2017.

7 Key results and discussion

We have five ways of trying to obtain reliable information on the benefits of the VIA (Table 5). When visiting schemes, we invariably hear the 'success stories' and many of these have been captured in print. A typical example from Tanzania is below.

Before, I could harvest only 12 bags of maize in a season, which earned me Tsh 480,000 (about US$218). Today, the harvest has increased to 30 bags, which translates to Tsh1, 200,000 (about US $ 545) when sold at Tsh 40,000 (about US$ 18). I have reduced the frequency of irrigating from three times weekly to once per week. I have also reduced the amount of fertilizer applied from three times (about Tsh 339,000 or US$ 154) to only twice (about Tsh 201,000 or US$ 91) now. Because of these changes, I have spare time to make mandazi (African dough-nuts), which earns me Tsh40, 000 (about US$ 18) monthly. During the planting and harvesting seasons, I employ seven to eight people in my farm.

These stories of more than doubling yield and more than halving water are common, as are the claims of reduced fertiliser use, saving time, reduced conflict and hiring more people. Yet it is difficult to know how widespread these gains are or how well they can be sustained post project.

Focus groups are more reliable (row 2 in Table 5), but they also tend to select towards the more successful outcomes. Focus groups allow us to get opinions not just of participating farmers, but also scheme managers and extension workers. This can be more objective, but results are still hard to quantify.

Table 5. The benefits claimed due to the VIA based on how the data is collected, the associated dilemmas and how the information can be interpreted.

Method	VIA Benefit claimed	Dilemma	Interpretation
Interviews	Extraordinary	Cherry picking	Massive changes are possible and those who get them are vocal
Focus group	Excellent	Self selection	Easier to believe big stories if there are credible reasons to back them up
On-scheme trials	Very Good	Expensive	Accurate, but researcher run trials tend to give best case scenarios
Questionnaires	Mostly good	Gifting /gaming	Large sample size, but not always clear that farmers fully understand the question (or the purpose)
VIA data analytics	Mostly good	Time consuming	Powerful and Objective. Some aspects prone to errors but this may be overcome by the large sample size.

On-scheme trials (row 3) are expensive, but necessary to provide information in the form that most donors want, in our case as a change in water productivity. Water productivity is defined as yield divided by water use, although the definition can be rubbery, as we see below.

Using data from VIA trials and sister projects in Africa, we now have a number of strong examples of how yields have increased and how water has been saved. Yet even these trials need to be interpreted with care, depending on how the 'control treatment' is framed (Table 6). In Mode 1 research, the control treatment is often best practice, such as a tensiometer, hence the Chameleon just has to match that. In Mode 2 research, we have genuine farmer managed plots, with all the attendant constraints, and the impact of the VIA can be huge. Researchers aiming to mimic farmer practice when doing trials on schemes are mixing Modes 1 and 2. They may use the same irrigation interval and use the same fertiliser, but the agronomic attention to detail results in much higher yields.

Table 6. Interpretation of benefits needs to take into account the nature of the ‘control’ treatment.

Research Mode	Location	Manager	Control treatment	Benefit
Mode 1	Research station	Scientist	Tensiometer	Small
Mode 1/2	On Scheme	Scientist	“Farmer practice”	Medium
Mode 2	On Scheme	Farmer	Farmer practice	Large (potentially)

Results from Mode 2 research have shown changes in Water Productivity among VIA farmers that are much higher than anyone could have anticipated. The data below comes from reasonable sample sizes (usually 15-20 farmers) over a four-year period drawn from the VIA and TISA projects. Average yields may go up from one third to more than double. Water use can be reduced by more than half, leading to seven-fold increases in Water Productivity. The main conclusions we can make from such data is that i) current practice is very poor and ii) the VIA tools are highly effective in improving WP - when starting from a low base.

Table 7. The increase in yield and decrease in irrigation average across approximately 15 farmers (Mode 2) or from replicated trials (Mode 1, 1 and 2).

Country	Crop	Research Mode	Increase in yield (%)	Decrease in irrigation (%)	Increase in Water Productivity (%)
Zimbabwe	Maize	2	36	61	350
Zimbabwe	Maize	2	135	59	570
Mozambique	Green Maize	2	239	53	710
Tanzania	Green Maize	2	28	64	360
Malawi	Maize	1 and 2	68	49	330
Malawi	Beans	1 and 2	31	41	220
Malawi	Maize	1	3	22	34

The Mode 1 research gives us numbers closer to what we may expect. In this case for Malawi in Table 7, the control treatment is a full water balance calculation with weather inputs, and the crops are grown on a research station. In this case, yields were not improved by the Chameleon, water use was slightly lower, and WP about one third higher. Research that includes both Modes 1 and 2 involves researcher run trials on farmer plots and tend to give intermediate results.

The problem with the data in Table 7 is that each line of data above costs many thousands of dollars to obtain. Moreover, the apparently ‘hard’ numbers are not has hard as we may think. It’s not easy to obtain accurate yield estimates from variable farmer fields. It’s many times harder to get accurate estimates of irrigation applied from furrows, requiring measurements of siphons, flumes, dates and durations of each event and a skilled operator in attendance. Rainfall cannot be omitted from water use calculations, yet its effectiveness in replenishing the root zone is very different from irrigation (large events than run off, small amounts that evaporate). Including or excluding stored water adds another complication.

Questionnaires (line 4 in Table 5) are the way to get a large amount of data at minimum expense. Farmers are asked to answer a 5 minute survey after each monitored crop has been completed. We call this “Accreditation” because it can be done by someone outside our team, and act as an independent ‘check’ on the colour pattern and yield data recorded on the VIA platform. First we ask farmers questions for which we know the answers, like their past sequence of crops, and frequency of data collection (it’s recorded on the VIA). Then we ask them to rate their change in yield from before using the tools (using a visual aid). If yields are lower, they are asked to select one of 5 reasons. If yields are the same or more, they can list other benefits such as saving water, time or fertiliser or reduced conflict.

In some ways, qualitative data is more useful than quantitative water productivity data. We find out what is important to farmers. Farmers’ perception of improvement can be more accurate than our measurements, partly because of the ‘control problem’ described above. Even a short time after introducing VIA tools to some farmers in the scheme, many more farmers change practice through word of mouth. Very quickly there is no control treatment. Hence our accreditation questions ask farmers to estimate yield changes before and after the VIA.

The final questions ask whether the equipment is in good working order (so we can repair if necessary) and one open suggestion the farmers want to put back to the VIA team. The data is automatically collated online and displayed as below.

Figure 6 shows the accreditation data for Msolwa scheme in Tanzania. Farmers were willing to provide information on the last 95 crops. The majority estimated yield increases of 25 to 100%. Nine farmers estimate their yields were lower due running out of water, low use of inputs and pests or disease. The vast majority of farmers claimed to save water, time and fertiliser and that conflict was reduced. The questionnaires certainly help us to understand how widespread benefits might be, but not all the data can be taken at face value. For example, accreditors have overhead farmers asking each other “what are the correct answers to give?”

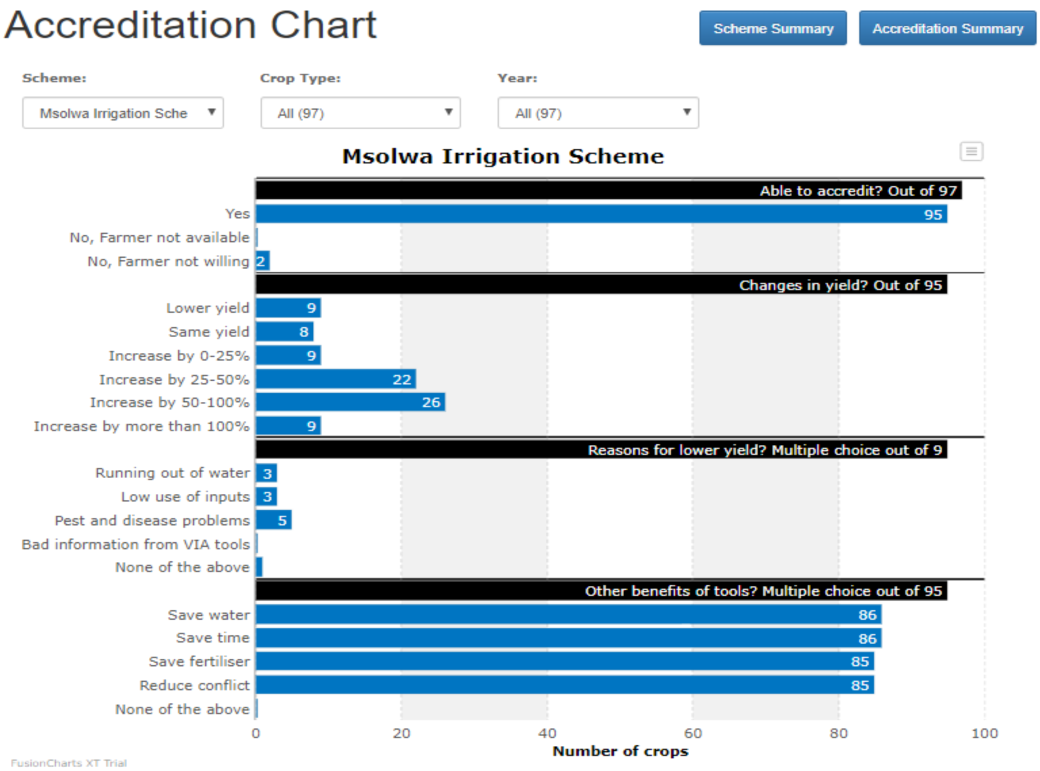
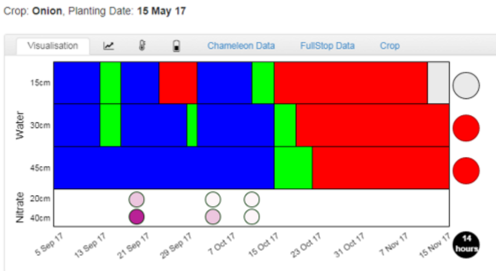


Figure 6. Accreditation Chart for Msolwa scheme in Tanzania

Finally, we get to the VIA data analytics as shown below, as data from Chameleon and other sensors is aggregated from day to season to scheme in order to identify problems and monitor progress.

1. The Chameleon Reader

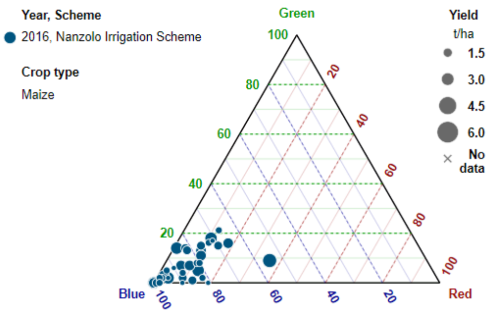
A Chameleon sensor array is comprised of three sensors placed at different depths in the root zone. The sensor array is connected to a reader and the water status at each depth is represented by LEDs which show blue (wet soil), green (moist soil) or red (dry soil). These readings are taken by the farmer or extension worker.



2. The Chameleon pattern

Each sensor array has a unique ID chip and the Reader is Wi-Fi enabled, so the data is sent to the VIA platform and collated for each crop. This produces a three-layer Chameleon pattern over time.

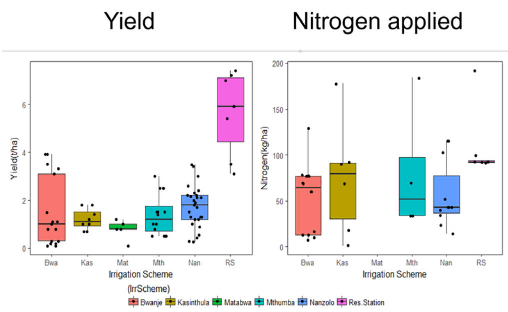
The white/pink/purple circles show the Nitrate status from water samples captured by a Wetting Front Detector, measured using test strips.



3. The Scheme Triad

Each Chameleon pattern above can be collapsed into a single value by integrating the area of blue, green and red and displaying on a triad diagram. In this diagram, all the maize crops from Nanzolo scheme, Malawi, in a given year can be viewed together (in this case grouped towards the blue corner indicating persistent over-irrigation), with the yield shown by size of the dots.

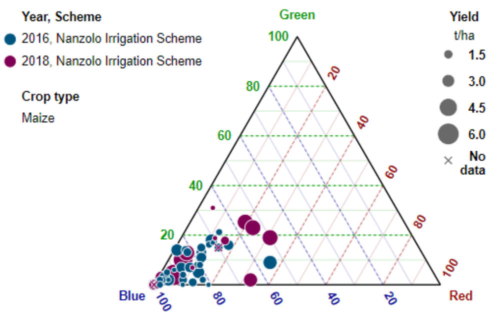
Over-irrigation leads to nutrient leaching, which is examined further below.



4. The multi-scheme comparison

We compare each scheme using box plots, which show yields divided into quartiles and the median value for each scheme. This data can be correlated against fertilizer management, and varieties to investigate the cause of yield gaps, using the research station (purple) as the benchmark.

In this case, we show yield (left) and nitrogen fertiliser applied (right). The analysis shows that low application of N fertiliser is not the primary cause of low yields.



5. The multi-year comparison

By comparing two triads showing the same crop at the same scheme over different years, we can see how water management practices and yields have changed in response to the VIA tools.

In this case, we see a shift in some crops away from the blue corner, showing that the farmers are using less water. We also see an increase in yield (2018 dots are larger).

The information shown on the previous page has different intended audiences. Table 8 shows 4 different 'levels' of VIA user, the VIA service that can be provided and the decisions that could flow. Each level has different requirements. Farmers (Level 1) are rarely interested in Water Productivity. They are interested in the marginal rate of return to inputs, including labour which can be more profitably used off-farm. There is usually no incentive to save water, which is basically free in gravity schemes, but they are highly motivated to save time.

Scheme managers are under pressure to provide equitable supplies of water to farmers in different parts of a scheme. Perceptions of mistreatment and conflict are common on schemes and undermine the social capital needed for cooperation and joint action, such as repairs and maintenance. Governments (Level 3) are interested in Water Productivity, especially when there are competing users such as downstream schemes and hydropower.

Donors (Level 4) building or repairing irrigation schemes typically spend $5,000 to $10,000 per ha. They have mandatory reporting requirements on the performance of these investments, but there is little record of crops grown on the schemes or yields. There is never any information on water use.

Table 8. The different services the VIA can deliver to different users

VIA Level of User	VIA service provided	Type of decision making
Level 1: Farm scale	Farmers learn to manage their water more efficiently by comparing their Chameleon colours with their own crop performance.	Should I irrigate today? Did I irrigate too much or too little? How will I irrigate next time, next season?
Level 2: Scheme scale	Scheme management learn by comparing colour patterns and yields across the scheme to find more equitable and efficient management practices.	Is the scheme running out of water or overwatering? Which blocks are performing well? Who is disadvantaged?
Level 3: Governance	Data provided on irrigation scheme performance across a country. The way water is managed at the highest level nationally.	Which irrigation schemes should be prioritised for intervention? Benchmarking of schemes.
Level 4: Major projects	Automated reporting provided to large donors who have need to track performance of their water investments.	Monitoring and Evaluation. Investment planning

In summary, quantifying the benefits of the VIA involves interviews, focus groups, water productivity experiments, accreditation questionnaires and VIA analytics. Yet we make the case here that the VIA analytics is central and effectively 'connects up' the other methods. For example, the 'Triad' diagram in Figure 7 summarises the performance of green maize at three different sites. The position of the dot in the triad shows the integral of blue, green and red colours through the season. The size of the dots represents yield.

The site "2018 Green Mealies" was an irrigation trial and reveals fairly high yields obtained from a watering regime that put it in the centre of the triad. But as irrigation amount was reduced, the Chameleon patterns show more red and the yields decline as the percentage red exceeds 50% (and the dot migrates towards the red corner). The site "2016 Bwanje" had numerous crops all 100% blue (all plotting on top of each other) and produced a low yield. The site "2017 Kiwere" shows higher yields both in the blue corner and towards the centre of the triad.

The aim of this example is to structure a conversation about what is happening on the schemes (position in the triad and size of the dot) and then to hypothesise why. 100% green is the best location in a triad, because green represents adequate water with no possibility of leaching. But it's impossible to stay in the green; if water is applied the pattern goes blue and if it is withheld the pattern goes red.

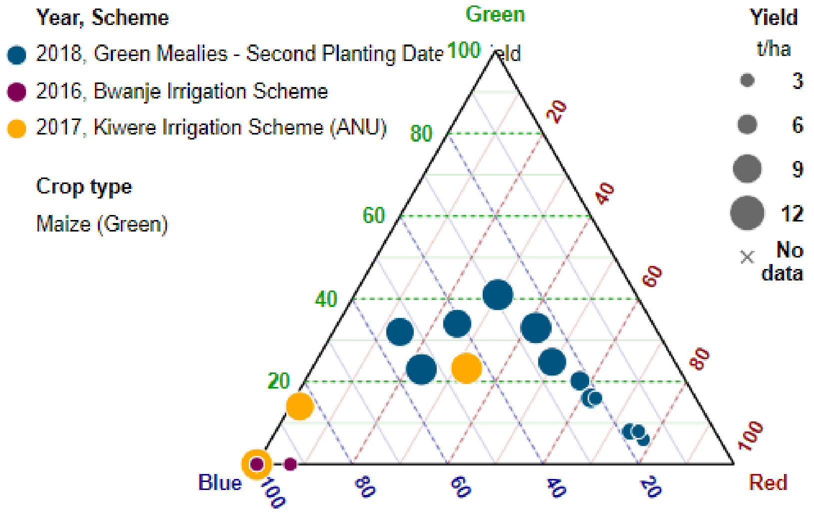


Figure 7. An example of VIA Data Analytics, showing data for three different sites growing Green Maize.

Farms at Bwanje scheme (red dots) are very wet and get low yields, and we may presume there is excessive leaching. Some farmers in Kiwere also got high yields in the blue corner. It's possible they manage to stay blue without much leaching, or they may have used more fertiliser. The point is that the triads suggests options, based on the current position in the triad and the yield.

For researchers, irrigation is a science. For farmers, who face site specific constraints and opportunities, irrigation is an art. The VIA connects the science and the art.

Triads such as the one above can be useful in explaining science to farmers. But it is even more useful in capturing the innovation of the farmers, and interpreting this in the light our scientific understanding.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The VIA encapsulates scientific advances in basic, applied and action social research as outlined in Figure 8. The basic research has involved the selection of the sensing material between the electrodes. We investigated numerous different materials that lost large amounts of water in the tension range of interest, i.e. 10 to 60 kPa (the range of a tensiometer). We found a material that had a 60% change in water content, when in equilibrium with a soil that was changing just a few percent. The sensing material is essentially a signal amplifier which takes a relatively small soil water signal (say drying from 15 kPa to 20 kPa) and provides a large change in resistivity. This opened the door for a simple sensor design and circuitry to read the sensor. We built sophisticated testing rigs involving bubble towers in parallel connected to tension tables. This allowed us to implement rapid and precise changes in tension on a test bed material for the screening of sensing materials. Later this same apparatus was used to fine tune sensor design.

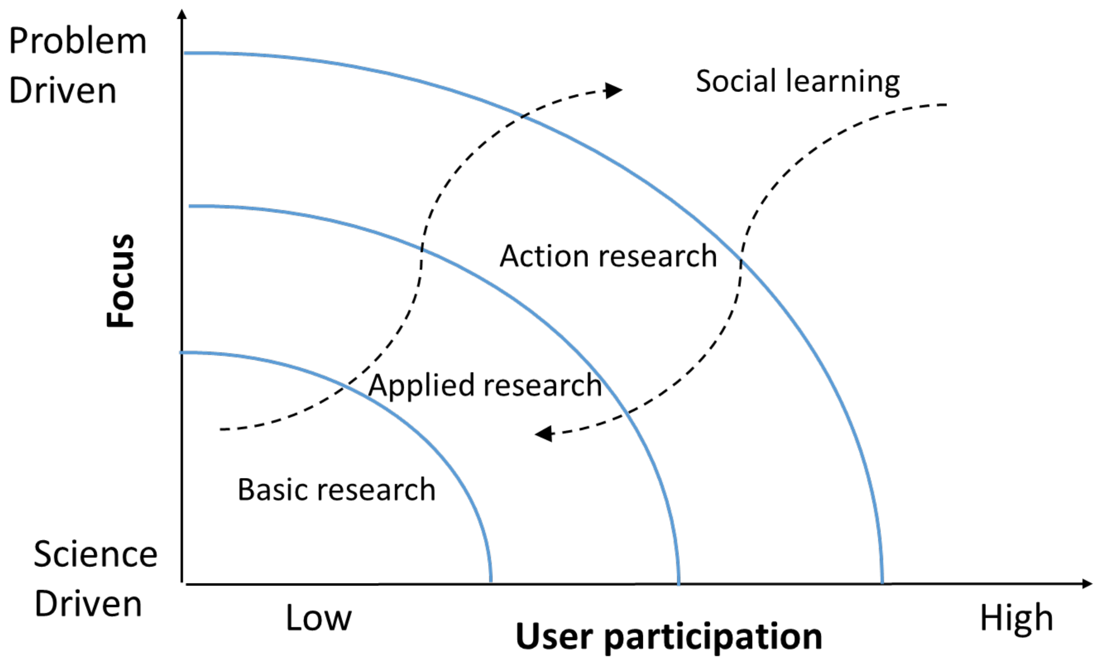


Figure 8. The VIA operates across the science-driven and problem-driven domains, and from disciplinary experts to many different users (redrawn from Kirchoff et al 2103).

Examples of applied research include the use of inexpensive micro controllers (ATmega328P; $1.86), to read multiple sensors, store data, visualise data by LED and screen and send data to the cloud. There were innumerable iterations in the design, development and coding to get the full system stable off a single lithium-ion rechargeable battery.

Examples of action research include the use of colours as thresholds for action for managing water, nitrate and salt on schemes. This effectively created a new language for talking about irrigation that connected the community of practice. It allowed ideas to spread rapidly and quickly embedded new ways of doing things.

The VIA tools and platform have developed so rapidly over the last three years that it is almost impossible to say where we will be in five years' time.

8.2 Capacity impacts – now and in 5 years

Farmers claim major changes have taken place at irrigation schemes in response to Chameleon colours, even in the first season. We do not fully understand why they are so confident to change. A typical story is as follows: While standing in his maize field, the farmer (Figure 9 top left) says he normally would have irrigated his crop 12 times, but this dry season he had irrigated just 3 times because the Chameleon was predominantly blue. We asked why he believed the Chameleon colours he shook the maize stems and answered ‘because I can see’. Clearly there is some local validation operating which is totally different from the validation required by a scientist.

Figure 9. Examples of farmer training from the field to the classroom.

When visiting the field, the farmer will talk at great length about complex issues like salt and salinity (photo top right: the farmer has a nitrate strip in his right hand and an EC meter in his left hand). Farmers spoke with great authority about nitrate leaching. Extension workers usually stayed in the background, suggesting that experiential type learning went much deeper than any formal training had.

We once invited a group of farmers to address us at an annual meeting (photo bottom left). After 30 minutes we thanked them in order to move onto the next item, but they refused to leave the stage because “the still had more to say”. In the end, the Director-General walked onto the stage with a Chameleon pattern on his laptop to try and counter a farmers point, but this just created another round of discussion. The farmers were more than happy to take on the director and his interpretation.

These few stories are just to illustrate that we still know very little about Mode 2 learning and how research teams will need to operate across both Modes 1 and 2, something many scientists find difficult to do.

As shown in Figure 1 (Background), we had 68 sensor arrays sending us data in 2015 and 1840 sensor arrays sending data in 2018. The capacity impacts in five years' time will depend on how successful we are in finding others with a mandate for improving water productivity to partner with us.

One of the major capacity impacts is that farmers without VIA tools also change practice. Having less than a quarter of farmers on the scheme with equipment usually benefits the entire scheme. The example from the TISA project in Zimbabwe in Figure 10 shows the dramatic reduction in irrigation by farmers with VIA equipment over a three-year period. However, neighbouring farmers, without equipment, also reduced their water use. The reason is that these farmers are growing the same crop on the same irrigation supply canal. If a farmer who is measuring soil water decides to skip an irrigation (and several hours of work) then a neighbour is inclined to skip too.

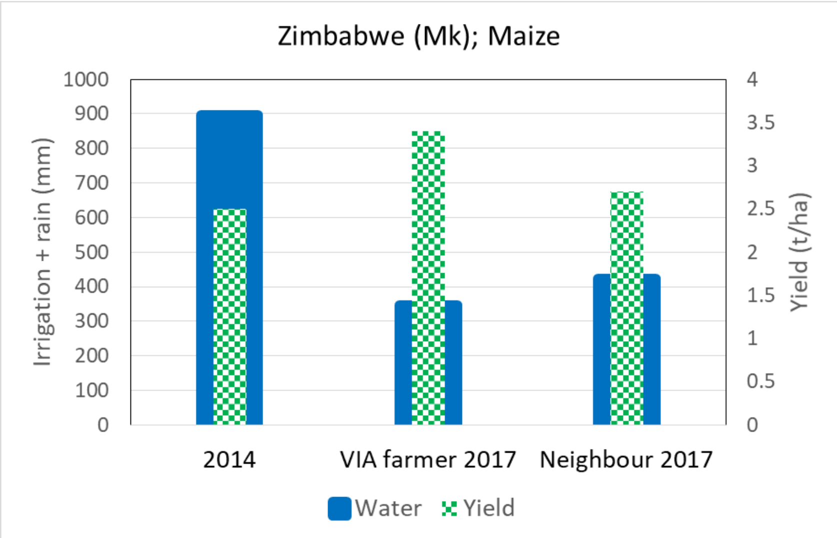


Figure 10. The irrigation and yield before the tools were installed in 2014, and the situation for farmers with tools and neighbours without tools in 2017.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Any economic benefit comes at the end of a sequence of changes in irrigation and fertiliser management. Figure 11 shows gross margin data for two schemes in Malawi for dry beans and grain maize. Despite the many things that need to work together for a profitable crop (e.g. the fall army worm devastated maize crops in 2017), we see significant economic benefits in one year and these continue to improve. However, economic benefits go well beyond crop gross margins. For almost all farmers, irrigation farming is only one income stream. They are not trying to optimise one activity, but to spread their risk by investing time in other income generating activities such as brick making, selling cooked food, and time at the market. Thus farmers rate saving time through less irrigation as one of the biggest benefits of the VIA.

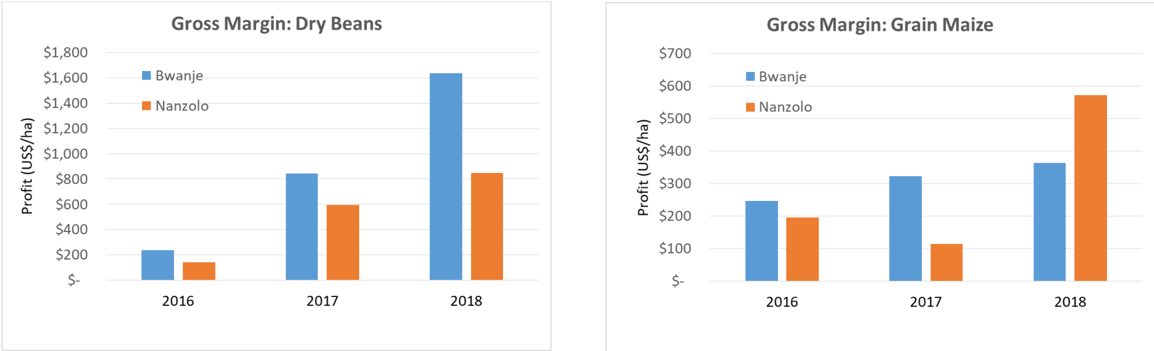


Figure 11. Gross margin of beans and maize at Bwanje and Nanzolo schemes in Malawi.

Our expectation is that the economic benefits have only just begun and will continue to increase over the next five years.

8.3.2 Social impacts

The social impacts are widespread and captured in Figure 12 from Bjornlund (2018). At the top left is the introduction of "VIA tools" which sets off a cascade of benefits including a reduction in watering, labour saving and increased time spent weeding. On the right-hand side is a loop mediated by Agricultural Innovation Platforms that results in higher yields and incomes. The social dividend at the end includes a decrease in conflict within the household and across the scheme; improvements in food security; more spending on education and the home; increased hiring of non-family labour; collective action in buying and selling; willingness to pay irrigation fees; greater participation in scheme maintenance activities.

The role of scheme extension workers is also changing. Extension has historically been difficult as it can be a poorly paid job having limited support. Extension workers who are assisting with Chameleon readings have remarked that they have increased status at the schemes and farmers also benefit from more face to face contact.

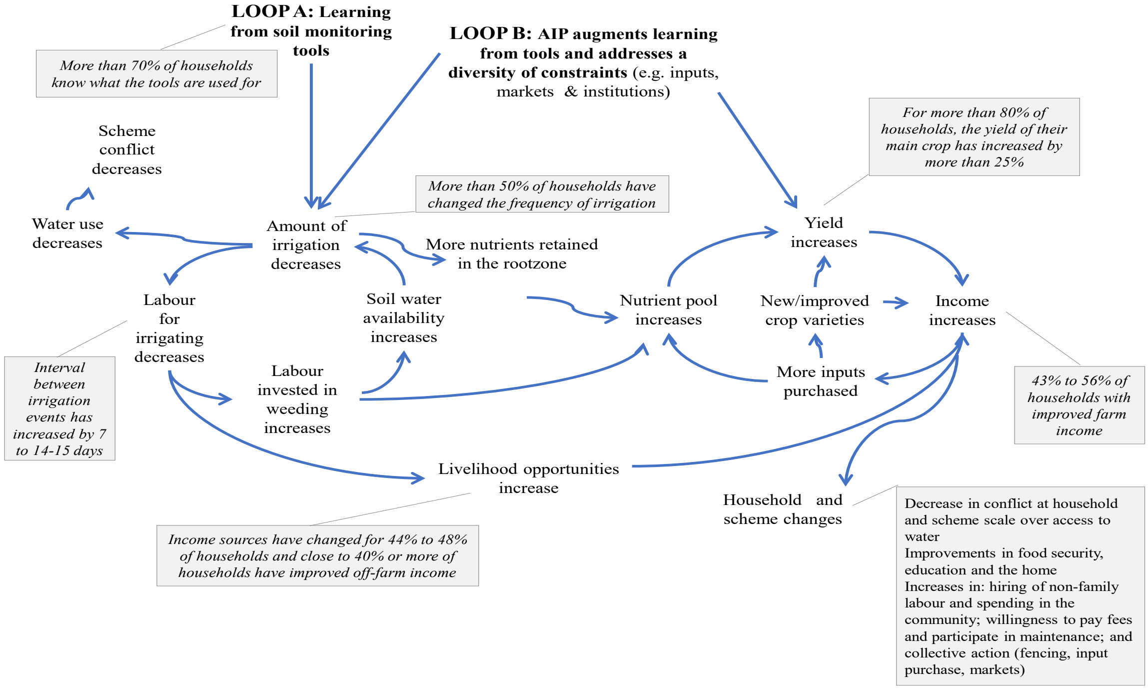


Figure 12. The cascade of benefits flowing from the introduction of the VIA tools (from Bjornlund et al 2018).

Conflict over water is serious but poorly understood feature of life on irrigation schemes (Figure 13). Farmers have to cooperate over water delivery schedules, paying fees and maintenance of canals. They also benefit from the joint bulk purchase of inputs and cooperation during selling. For example buyers often try to force farmers to compete amongst each other for vegetable sales, whereas an organised scheme with market knowledge can set a floor price for each crop and agree not to undercut one another.

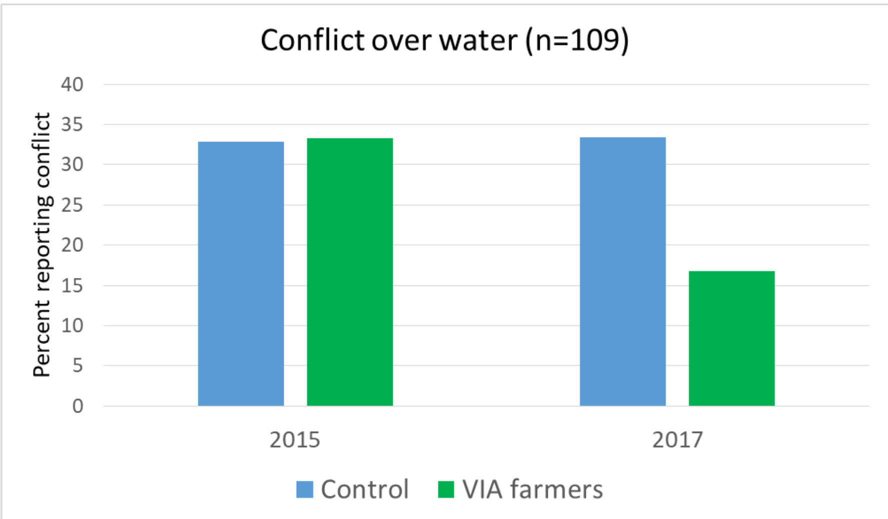


Figure 13 Changes in farmer reports on conflict at schemes in Malawi.

8.3.3 Environmental impacts

Irrigation has a massive environmental footprint. There is irrigation-induced salinity on several of the schemes, particularly Kasinthula, Kiwere and Buigiri, but we are yet to focus our work here. Our strategy has been first to engage the teams in understanding water, then the interaction between water management and nitrate movement and finally the combined interplay between water, nitrate and salt.

Most of the irrigation schemes are relatively small (<200 ha) and far apart, so the high water tables and salinity are often of local scale. This means that local scale action (reduced irrigation) should have a fairly quick response. More detail on this is in the Master Thesis from Kasinthula sugar estate by Trencio Kandinga.

The recent introduction of our Chameleon salt meter, which displays electrical conductivities by colour, is a big step forward in helping farmers understand the consequences of poor irrigation practise.

The massive decline in water use described throughout this report will undoubtedly have a beneficial environmental impact. However, many of the schemes have reported that saved water is being used to either extend the irrigation season or irrigated area. Thus impacts are more likely to be seen in food production rather than water saved.

8.4 Communication and dissemination activities

The VIA platform is a powerful internal communication system and connects up all the users around the world.

The VIA has three Super Users in Canberra and two in Africa who have access across the entire site and monitor activity from the more than 200 separate locations where equipment has been installed. Each of our focus countries has a VIA Country Manager who is specially trained to set up schemes on the VIA, carry out data quality control and do basic troubleshooting. The Country Managers have a weekly Skype call with Canberra to go through any problems.

Those installing sensors and collecting data at individual schemes allocate farmers to irrigation plots, crop types and sensor IDs on the VIA and report to the Country Manager. Project members who need to see their data are designated as ‘users’ and have password protected access to the sites they manage. Site managers can choose to make their site public, in which case it can be seen by any public visitor to the VIA site. However, when ‘public view’ is selected, all farmer names and identifiers are hidden for privacy reasons.

Since there is no delay between a farmer taking a measurement in the field and the colour patterns being generated on the VIA, the project teams are in constant dialogue over data interpretation, anomalies and surprises. We are constantly trying to improve methods for rapid detection of problems, or better ways to visualise data.

The VIA platform is a monitoring and evaluation system at many levels. Since the VIA is fully digital, we can track all key metrics including:

1) number of sensors produced
2) sensors actively being monitored on farm
3) the soil water status of these crops
4) the relationship between soil water status and yield
5) whether water use and crop yields are changing over time
6) yield gaps within and between schemes

7) identification of places where direct interventions are required i.e. very low yields, high water use
8) identify where infrastructure is failing
9) identify where schemes are badly managed.

Thus the platform operates as both an **accountability system** (how we are progressing with implementation) an **evaluation system** (tracking the success of the interventions).

9 Conclusions and recommendations

9.1 Conclusions

We have evaluated the benefits of the VIA through interviews, focus groups, on-farm experiments, accreditation surveys and VIA data analytics. In all cases, the VIA has gone beyond our expectations. We are also well aware that the small scale irrigation sector has historically underperformed and many previous interventions have not had a lasting impact. Thus we need to assess whether the reported benefits of the VIA are real, widespread and able to be sustained beyond the life of the project.

Our on-farm trials show that water productivity has increased between 200 and 700%. Based on our accreditation survey covering over 400 crops, farmers estimate that yield of 78% of crops has increased by more than 25%, despite problems of pests and diseases and low use of purchased inputs. Thus the data strongly suggests that benefits are both large and widespread. It remains for us to come up with a plausible explanation.

The first and most obvious impact of the VIA is farmers see that their fields are wetter than they expected. For those farmers with WFDs, which have been less widely distributed, the rapid change of the nitrate test strip from purple to pink has also made a dramatic impact. Many farmers were able to connect these two observations i.e. too much water keeps the Chameleon blue and too much water leaches the nitrate.

These observations have revealed new opportunities, which in turn triggered a cascade of other changes shown in Table 9. A farmer could easily test the idea of a field being too wet by skipping an irrigation event, and then observing the condition of the crop and subsequently the Chameleon readings. In most cases the outcome was a healthier looking crop and less angst over perceived shortages of water across the scheme. This occurred surprisingly quickly, often within the first crop where the tools were deployed.

Table 9. The cascade of opportunities and outcomes following introduction of the VIA

	First crop	First Year	Second Year
Observations	Chameleon is blue N strip is white	Saved time Retain nutrients	Extension worker engagement Scheme level cooperation
Opportunities	Skip irrigations Rethink nutrition	Off-farm income Scheme level changes	Youth interest in scheme Increase land under irrigation
Outcomes	Better crops Reduced conflict	Increased income More employment	Change in mindsets Increased scheme viability

After a year or so, farmers started to explain the other benefits of skipping irrigation, such as saving time, which then allowed more weeding and other good agronomic practices. Saved time was also put into off-farm income generating activities, and some of this income could be invested back in the farm.

Extension workers taking Chameleon readings reported they had greater status on the schemes and farmers said they benefitted from more frequent contact with extension officers to get information about inputs and crop choices. Scheme management committees noticed that the benefits to the scheme as a whole could be greater than the sum of participating farmers. Some schemes introduced cropping programs that made it easier to distribute water throughout the scheme and extended the irrigation season.

Thus we see that simple intervention of displaying water and nitrate as colour patterns can open a set of new opportunities with mutually reinforcing outcomes. In a relatively short space of time, the learning from a minority of farmers can cascade through to substantially changed mindsets and practices on irrigation schemes and underpin the viability of smallholder schemes.

Like any information system, the VIA has a cost. The seminal question is, can the VIA be sustained from the bottom up, through farmer purchase of equipment? We believe not. We also believe that confining the benefit to individual farmers is missing the greater opportunities because higher order obstacles limit the profitability of the sector.

Thus we are developing a suite of data analytics products that can connect the VIA to those who have the capability to implement it at scale. The strategy is to subsidise the monitoring tools to farmers and the data collection through selling the data service to scheme management boards, governments and donors who invest in infrastructure. Essentially we will create five value propositions for five clients as follows:

1) Farmers, who will be able to increase yield through better water and nutrient management using colour data from the sensors;
2) Scheme managers, who can optimize the delivery of water across a scheme to meet farmer requirements;
3) Governments, who need to know how profitable and water efficient their schemes are, where to intervene with targeted extension services and where to invest in repairs;
4) Researchers and NGOs running their specific projects; and
5) Infrastructure donors who must track the internal economic rates of return of large irrigation investments.

We believe that the water sector is currently constrained by the absence of information that can connect the interests of farmers, scheme managers, researchers, investors and governments, who are the five ‘clients’ of the VIA. There is no accountability system in place that can track the productive use and governance of water for irrigation, and hence no feedback from which to learn and improve.

9.2 Recommendations

The recommendations from Phase 1 of the VIA project have been factored into the objectives of a VIA phase 2 project in the process of being contracted with ACIAR.

The VIA Phase 2 objectives are as follows

1. Continue R&D and refinement of the VIA tools and platform to make it more robust and user-friendly
2. Increase the capacity and reliability of the Chameleon production line in Africa for the growing community of VIA users worldwide.
3. Build cost-effective ways to roll out the VIA to irrigators and obtain quality-controlled field data at larger scale.
4. Develop the data analytics that capture the value proposition for each of the five ‘clients’ of the VIA.
5. Create the business models and organisational structures that can deliver the VIA irrigation learning and governance platform.

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10.2 List of publications produced by project

Publications are in progress, although most of the work done by the VIA team is published under the TISA project.

11 Appendixes

11.1 Appendix 1:

See Project Sharepoint site for review

https://aciar-y.sharepoint.com/personal/robyn_johnston_aciar_gov_au/_layouts/15/onedrive.aspx?id=%2fpersonal%2frobyn_johnston_aciar_gov_au%2fDocuments%2fLWR+2014+085+VIA&FolderCTID=0x01200044202159D0436F48B30C34FA8CCA7AB2