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Final report

project

Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and Agricultural Innovation Platforms

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Contents

Acronyms

ACIAR	Australia's Centre for International Agricultural Research
AGRITEX	Agricultural Technical and Extension Services, Zimbabwe
AIFSC	Australian International Food Security Centre (part of ACIAR)
AIP	Agricultural Innovation Platform
ANU	The Australian National University
BACI	Before-After-Control-Impact.
BPC	Bulawayo Projects Centre
CAADP	Comprehensive Africa Agricultural Development Program
COMESA	Common Market of Eastern and Southern Africa
CSIRO	Commonwealth Scientific and Industrial Research Organization
DFAT	Department of Foreign Affairs and Trade
DoIRR	Department of Irrigation
FANRPAN	Food, Agriculture and Natural Resources Policy Analysis Network
FAO	Food and Agriculture Organization of the United Nations
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
INIR	National Institute for Irrigation in Mozambique
IO	Irrigators Organisation
IWMI	International Water Management Institute
MAFC	Ministry of Agriculture Food Security and Cooperatives
MAMID	Ministry of Agriculture, Mechanisation and Irrigation Development, Zimbabwe
MKILMA	Mkombilenga, Ilolo Mpya and Magozi Irrigators Association
MUVI	*Muunganisho wa Ujasiramali Vijijini* (Rural Business Support Services)
NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organization
QDS	Quality Declared Seeds
R&D	Research and development
RUDI	Rural Urban Development Initiative
SADC	Southern African Development Community
UEM	University Eduardo Mondlane, Mozambique
USAID	United States Agency for International Development
WFD	Wetting Front Detector
WP	Water productivity

1 Acknowledgments

All project partner organisations provided invaluable contributions to the project and we thank them for their time and effort. The project outcomes were achieved due to the enthusiasm and hard work of project team members and the support provided by many others, including members of partner organisations and project stakeholders.

Our greatest appreciation is to the smallholder farmers from irrigation schemes: 25 de Setembro and Khanimambo in Mozambique, Kiwere and Magozi in Tanzania, and Mkoba and Silalatshani in Zimbabwe, who generously gave their time, knowledge and hospitality to the research. We are grateful for their co-operation and interest in the project. The research also benefited enormously from the assistance and support of irrigation associations, village leaders, local, provincial and national governments, extension officers, non-government organisations, input suppliers, financial and market representatives.

In particular, we acknowledge the financial support from ACIAR. The tremendous encouragement, advice and support provided to the project team by the ACIAR Research Program Manager for Land and Water Resources, Evan Christen, was greatly appreciated.

2 Executive summary

The project was developed to test a specific combination of technical and institutional change methods to increase irrigation water productivity and profitability in African smallholder irrigation schemes. This combination of 'Tools + Agricultural Innovation Platforms' (TAIP) has positive synergies that were found capable of reinvigorating failing irrigation schemes.

To achieve better yields with reduced losses of water and nutrients, smallholder farmers have been helped to monitor and understand the water and nutrient levels in their soils by using two inexpensive, simple to use tools: the Full Stop soil wetting front detector and solute collection device, and the Chameleon tool that measure moisture at different depths in the soil profile and displays the result as coloured lights; blue (wet), green (moist) or red (dry). Farmers used these to learn the best combination of fertiliser application and irrigation for their crops on their soils, and so increased their yields.

In order to overcome system issues, such as lack of access to markets, the project tested the effectiveness of structured opportunities for dialogue and problem solving between smallholder farmers and a diversity of other stakeholders through Agriculture Innovation Platforms (AIPs). In an AIP, the farmers identify one or more key barriers to better farming or opportunities, then invite relevant stakeholders who can effect change to discuss and agree on solutions. This means that farmers set the agenda for change. The AIPs have enabled farmers to lower input costs, identify more valuable crops and develop better markets so as to become profitable. AIPs tend to be time limited, but once a particular issue has been resolved through an AIP, the skills, experience and confidence to address other issues remain in that community. In the case of this project, the six established AIPs are still working through their desired reforms.

The 2016 external review of the project found that the research has enabled smallholder farmers and related stakeholders to 'achieve success in a traditionally difficult sector'. A key achievement has been that at five schemes, yield has improved two- to four-fold and farmer incomes have increased. In four schemes, unused irrigation plots covering an average of 27% of the command area were brought back into production. The frequency of water application was reduced by two-thirds at five schemes, and as a result, the supply of water to canal tail-end farmers improved so that they can produce crops reliably. As much as 70% of labour was saved from reduced irrigation frequencies and this time was often redirected into more intensive agriculture or small businesses. In focus groups the farmers reported greater social harmony among farmers and within households. Farmers began accessing certified seeds and using quality fertilisers at most of the schemes. A number of more profitable crops and crop varieties were grown. Through the AIPs, farmers enhanced access to crop processing facilities and markets. Maintenance of five of the irrigation schemes by farmers increased. Surveys showed that approximately 25% of the more than 1,700 scheme farmers were directly engaged in the project in the three countries, and another 55% received scheme-level aggregated benefits.

While these interventions in six schemes have succeeded with direct involvement from project staff, new research has now commenced in the Transforming Irrigation in Southern Africa project (LWR/2016/137) to learn and assess how these measures can be scaled out and up. There is a need to understand how to enable each national government irrigation agency to apply research lessons to their policies and practices. Further, engagement with multilateral African institutions is underway to draw on the research findings to improve their policies and practices.

3 Background

Feeding a growing and wealthier population with limited water resources while reducing rural poverty in Africa was the background to this project.

This project was designed based on the results from a scoping study that reviewed the work of IWMI, IFPRI, World Bank, Challenge Program, Gates Foundation and others on how irrigation could contribute to food security in nine sub-Saharan African countries (Pittock et al. 2013). The region seeks investment to increase the irrigated areas at six times the current rate under the Comprehensive Africa Agricultural Development Program (CAADP) initiative (Lankford 2005), and the land and water resources for such expansion are available (You et al. 2010). Set against these plans are: i) a history of irrigation in the region failing to provide adequate return on investment (Inocencio et al. 2007) ii) weak market integration and weak water governance institutions (Shah et al.2002) and iii) significant degradation and abandonment of irrigated land (Chilundo et al. 2004). Despite these drawbacks, irrigation expansion will take place, and so research is needed to increase water productivity (WP) (economic value per volume of water consumed) and mitigate environmental degradation in current and new irrigated lands.

There are no silver bullet interventions to improve WP in Africa. The irrigation 'problem' is systemic in that there is failure at several levels including technical capacity, institutional arrangements and market linkages. In response to such complex problems, the FAO (2012) called for the introduction of adaptive management approaches that will lead to social and institutional learning.

Of the nine countries reviewed in the scoping study, Mozambique, Tanzania and Zimbabwe were determined as best suited for the research. The selection was based on a combination of the following characteristics:

- National institutions that support the research approach of linking technological and institutional innovation;
- Strong, relevant in-country research capacity with good links to Australian institutions;
- Contrasting stages of irrigation development
- Capacity to engage relevant regional African institutions like CAADP and the Southern Africa Development Community (SADC).

African governments' priorities

In Mozambique, Tanzania and Zimbabwe the governments have made the development of irrigation a priority under the CAADP, which commits investment of 10% of national budgets to enhance agricultural production. Of CAADP's four pillars, this project focused on the use of so-called "blue water" (water removed from rivers, dams and aquifers) in pillar 1 and how this can best be utilised in the context of food security (making contributions towards pillars 3 and 4).

Mozambique currently uses just 0.3% of the total available water resource, with Tanzania using 6% and Zimbabwe 21%. When a country reaches 20-25% exploitation they are generally facing severe water scarcity, so these countries span the full exploitation range in the region.

Mozambique has large areas of existing irrigation that lie unused or salinized, as well as ambitious plans to expand the area under irrigation. Further, rapid economic growth is creating greater institutional capacities and also markets for agricultural production.

Tanzania also has ambitious plans to further expand the area under irrigation backed up by government policies and other support. Around 2.3 million hectares are classified as high potential for irrigation and 4.8 million hectares as medium potential. To date 345,690 hectares have been provided with improved irrigation infrastructure. Feed the Future

alone aims to increase area under irrigation in Tanzania by 15.5 percent through the development of seven smallholder irrigation schemes. Despite these expansion plans, water scarcity already limits production in key river basins.

Zimbabwe is embarking on the reconstruction phase of what was a relatively vibrant irrigation industry. There is a history of innovation in irrigation and agricultural production is expanding, but water scarcity is severe in much of the country.

4 Objectives

The overall aim of the project was to increase agricultural water productivity and improve food security in Mozambique, Tanzania and Zimbabwe.

The project's three objectives were to:

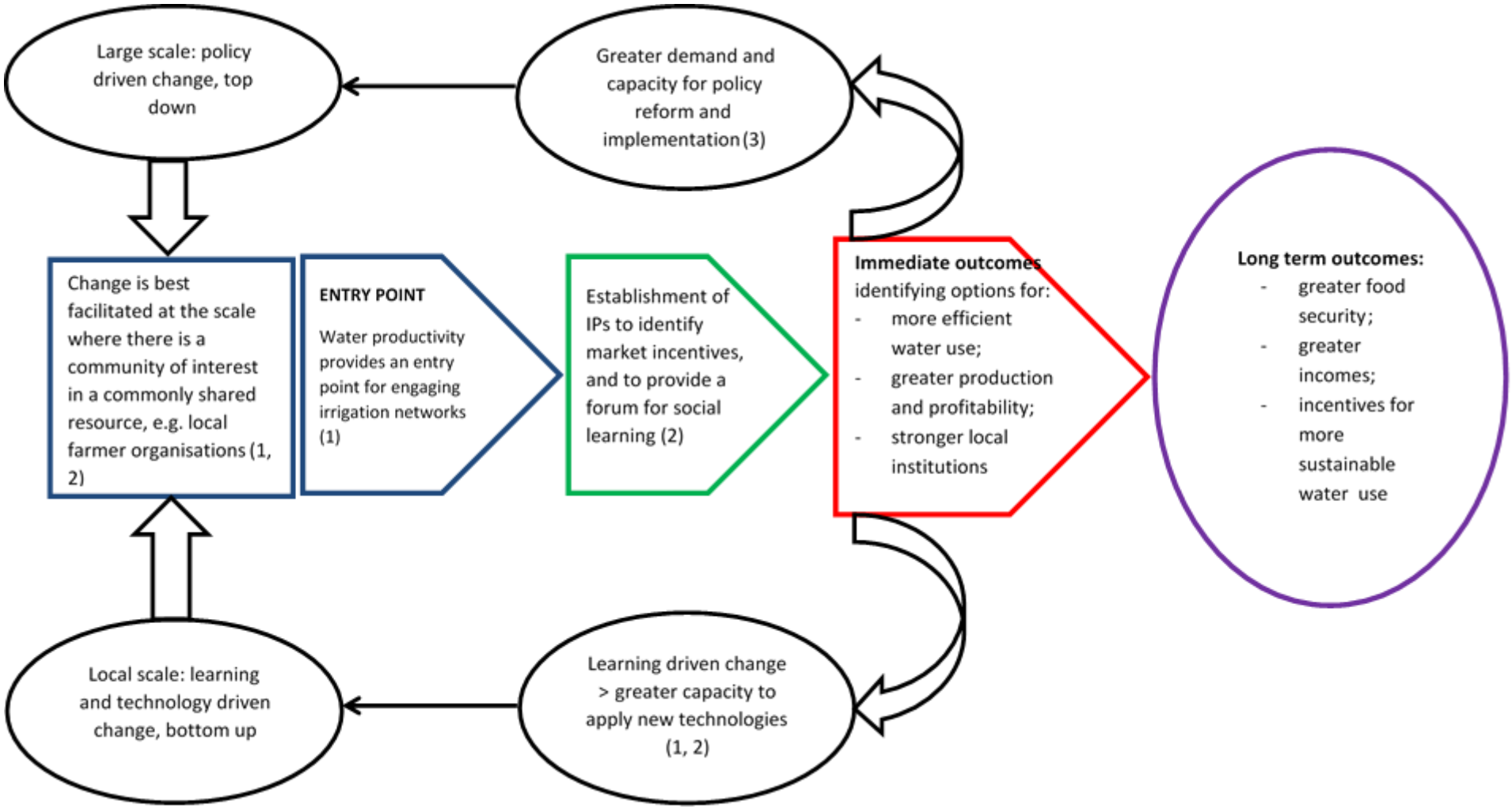
1. Evaluate whether Agricultural Innovation Platforms based on existing community organisations can identify and overcome institutional and market barriers to greater water productivity.
2. Develop, test and deploy water monitoring systems at each site as an entry point for enhancing agricultural productivity.
3. Identify and communicate economic and policy incentive mechanisms for greater water productivity

The objectives of the project were designed to respond to the strong criticisms that the 'technology push' approach is failing in Africa unless there is a concomitant focus on institutional blockages to progress (Byerlee 1998). The Forum for Agricultural Research in Africa (FARA) among others, argued for a change in the way research projects are implemented and asked the research community to move away from the business as usual model of knowledge generation by scientists – knowledge transfer by extension – knowledge adoption by farmers, in favour of the Agricultural Innovation Platform (AIP) approach. Papers from FARA (Adekunle and Fatunbi 2012) and other well-respected international groups (e.g. Hounkonnou et al 2012) presented powerful cases for following this research paradigm in the African context. In early 2013, ACIAR responded by sponsoring a workshop to identify how such an approach can be supported in practice, from which an innovation platform practitioners workbook has been produced (Makini et al. 2013).

The project's objective also relate to the project adoption pathway is outlined in Figure 1 below. For implementation the scale of intervention used was the irrigation community. This scale captures the interests of the community in terms of the shared resource and infrastructure. The entry point with farmers was increasing on-farm water productivity through monitoring soil water, nitrate, salt and water tables, in order to increase the yield and profitability of crops and minimise non-productive losses of water. Given that irrigation communities generally have weak institutional structures in Africa, the aim was to build them into larger AIPs that included market incentives. The different scales of issues frame the problem in terms of their long term goals (purple outline), the policy and institutional environment (top down) and the current technology, constraints and aspirations of the farmers (bottom up). The information from the monitoring and subsequent learning is expected to foster the intermediate outcomes of building capacity in the local institutions and the skill of the farmers (red outline).

The essential feature of Figure 1 are the two feedback loops. The first loop is directed upwards as the AIP creates better understanding through advocacy of the requirements and obligations for improved investment of funds or reform of policy (i.e. water licensing and/or pricing) – in other words, successful farmers put more pressure on governments to better service their needs. The second loop is directed downwards as farmers see how their practices impact individually on productivity and profitability, and collectively on sustainability. This creates the awareness and appetite to employ better skills and technology – in other words, as farmers livelihoods improve their capacity to innovate further increases. The time to impact was expected to be short as it will be driven by profitability, peer-practice and institutional changes.

Figure 1 Project theory of change (and related objectives in brackets)



5 Methodology

Location and description of study sites

The research was undertaken in three sub-Saharan countries of Mozambique, Tanzania and Zimbabwe, the selection of which is described in the background section. In 2013, twelve potential irrigation schemes were assessed as potential research sites – six in Zimbabwe, four in Tanzania and two in Mozambique. Site selection was discussed during the inception meeting in Maputo; and two sites were selected in each country (six sites in total). The criteria used included: smallholder irrigation; medium scale of the scheme; functionality of scheme infrastructure; diversity of crops; interest from local stakeholders; accessibility for researchers. The six irrigation schemes selected were: in Mozambique, 25 de Setembro and Khanimambo; in Tanzania, Kiwere and Magozi, and in Zimbabwe, Silalatshani and Mkoba (see Figure 2).

Figure 2 Map identifying the project irrigation scheme sites in the three countries

A summary description of each site can be found in Table 1, which includes hyperlinks to their locations on google maps. For further details on each scheme can be found on these hyperlinks for Mozambique, 25 de Setembro and Khanimambo; in Tanzania, Kiwere and Magozi, and in Zimbabwe, Silalatshani and Mkoba

Table 1: The irrigation areas assessed as project case study sites

#	Country / irrigation scheme with hyperlinks to map location	Area (hectares)	Type	Major crops	Farmer population
	Mozambique				
1	25 de Setembro, District of Boane, Maputo Province	Potential = 80 Developed = 40	River pumped - community,	Vegetables	38
2	Khanimambo, District of Magude, Maputo Province	16	River pumped and canal, community	Vegetables	27
	Sub-total	96+			65
	Tanzania				
3	Kiwere Irrigation scheme, Iringa District, Iringa Region	195	Canal, community	Tomato, onions, leafy vegetables, green maize, rice	168
4	Magozi Irrigation Scheme, Iringa District, Iringa Region	939	Canal, community	Rice	578
	Sub-total	1,134			746
	Zimbabwe				
5	Mkoba Irrigation Scheme (Gweru Rural District)	10	Canal, community	Maize, horticulture	75
6	Silalatshani Irrigation Scheme (in Insiza District)	442	Canal, community	Maize, wheat, sugar beans, and vegetables	845
	Sub-total	452			920
	Total	**1,682+**			**1,731+**

Methods

The methods and activities undertaken to achieve the objectives were as follows:

Cross-cutting project implementation.

0.1. Project management structures were established and an establishment workshop held. ANU (Dr Pittock) led the establishment of project management structures, including relevant sub-contracts, supporting staff recruitment, and briefing and developing operating procedures with project collaborators. A project coordinator (Dr Mbakwe) was appointed and based at the University of Pretoria. Workshops project collaborators were held in August and December 2013 to develop a common understanding and refine the project methodology. The initial workshop was facilitated by consultants, PICOTEAM.

0.2. The irrigation case study sites were reviewed and confirmed. The case study sites (listed in Table 1) were reviewed (by all participants led by ANU) to ensure that: they were the best places to undertake the research; a range of different irrigation practices are represented by the sites; the local organisations and people are interested in participating; and that we understood the history of past management at these sites. Six sites were selected for subsequent research.

0.3. Annual review. An annual project meeting was held to review progress, share knowledge across countries and collaborators, refine project operations and identify research findings. The meeting reviewed the project outputs and outcomes by scheme, country and overall.

Objective 1. Evaluate whether Agricultural Innovation Platforms based on existing community organisations can identify and overcome institutional and market barriers to greater water productivity.

Method. The AIP approach was used because there is a history of failure of uptake of improved technologies using traditional technology transfer approaches, and failure of irrigation schemes to achieve satisfactory crop yields, become profitable and be maintained. The aim was for farmers to identify and prioritise barriers and opportunities that they may be able to directly influence. These may include lack of institutional capacity, exposure to risk, inability to access inputs, lack of finance, inadequate markets for produce, and poor access to government services. Essentially the AIP approach is used when we want to simultaneously address technology, capacity and institutional issues that constrain adoption (Makini et al. 2013).

This work was led by ANU and ICRISAT, and project collaborators in each country. The first step was to define the overall problem or entry point, which in our case was water productivity ($/volume of water). Water productivity captures crop type, yield and value ($ returns) and the amount of water used. The amount of water used relates strongly to issues of equity (access to water) and environmental impacts but only weakly to economic returns, as the cost of water is usually a small component of total costs (although energy costs for pumping may be high, as in Mozambique).

The next step was to assemble in a local scale AIP the stakeholders who share a common objective in the prioritised issue, though they may have different individual interests. Identification of stakeholders involved social network analysis, gender analysis, market value chain analysis and focus group discussions to ensure that marginalised groups were identify and their interests were adequately considered.

Following the process of Makini et al. (2013), each AIP started with a visioning process to assess where each irrigation community is now and where it wants to be in five to ten years' time. Then the group identified barriers and roles that each of them could play in addressing these constraints and seizing opportunities. A number of the constraints were put to the research team with a request for us to help in identifying options for their resolution, including policy matters that the research team may take up in national and regional processes (Objective 3).

Each AIP needed a facilitator who could guide the diverse objectives towards the common vision, uphold transparency and who was aware of gender and power relations within and outside the AIP. This project tested three ways of providing that facilitation in terms of: a) an independent facilitator (Tanzania), b) researcher led facilitation (Zimbabwe), and c) government extension led facilitation (Mozambique). The benefits and issues with these different approaches were evaluated to communicate lessons for better facilitation practices and scale-up. ICRISAT and ANU developed a curriculum to train the facilitators in AIP methodology. Additionally, to address an identified gap in social sciences within the Mozambique team, their capacity was built in this area with the support of the University of South Australia (Bjornlund) the Universidade Eduardo Mondlane. These included training in value chain and economic analysis as well as increasing their capacity to use participatory tools for working with AIPs and farmers on irrigation scheme management.

The project did not compare improvements in water productivity between irrigation areas with and without the AIP process. Instead it undertook longitudinal studies of the six schemes by assessing the changes from baseline conditions to those after the implementation of the project with the AIPs in place. It also enabled comparisons between the six different local scale AIPs undertaken to identify elements leading to more successful processes. The links to policy are described under objective 3.

A number of surveys were undertaken beyond those originally planned (namely water productivity and agricultural production and livelihoods data) which greatly extended the research for development findings. This additional analysis examined the underlying

influences on household wealth and income, social networking and irrigation adaptation. Including these additional research questions helped to identify how change may be better facilitated in these communities and the causes of success and failure of AIPs.

Objective 2: Develop, test and deploy water monitoring systems at each site as an entry point for enhancing agricultural productivity.

Method. A participatory approach was used to test whether the combination of monitoring key attributes of the irrigation system coupled with enhanced capacity of local farming institutions can engender a positive, self-reinforcing cycle of adaptive management to enhance water productivity. The farmers involved in the AIPs at each site were invited to work with project researchers to measure water and solutes as an entry point for facilitating adaptive management to enhance agricultural productivity. Led by CSIRO and UP, and in- country collaborators, the project drew on and documented local knowledge. In particular the Chameleon soil moisture reader/sensor were further developed and used as a means of connecting farmer and researcher learning. Similarly the FullStop wetting front detectors were used to help farmers visualise their irrigation, fertiliser and salt management (see Table 2). The monitoring results were discussed regularly by the farmers and researchers to consider agronomic and water management adaptations to improve productivity. The farmers through their experiential learning, then applied adaptations including changed inputs of fertilisers and water, and use of different technologies. Because on-farm productivity also requires supportive off-farm institutions at different scales, linking this soil and water work in Objective 2 to the AIPs described in Objective 1 ensured that the changed practices are profitable and sustainable.

Table 2: Tools used in the learning systems

	The image is of the Chameleon reader and three white sensors which are buried in the soil at different depths. The Chameleon reader indicates the water stress that plants are experiencing at the various depths in the soil. The data are displayed as coloured lights (blue = wet, green = moist and red = dry). The Chameleon helps farmers to see how deep roots are extracting water, how deep irrigation water penetrates, leading to learning the optimal time and duration of irrigation. The current reader is Wi-Fi enabled and can hotspot off a phone and deliver the data to the website using the unique ID chip in every sensor array. The data is then collated and displayed in real time to give the 'Chameleon water pattern'. Phone apps are used to collect, store, display and share data so participants can learn together in real time. .
The FullStop Wetting Front Detector is buried in the soil and an indicator pops up when it captures inside the funnel a sample of the infiltrating water from irrigation. This water can then be extracted for measurement of salt and nitrate. The FullStop Wetting Front Detector is a CSIRO-developed tool that is commercially available.	
	Nitrate colour test strips are used to test the water collected by the FulltStop. The reading show farmers the nitrogen status of their soil and help minimise leaching of expensive nutrients. These are commercially available.

Objective 3. Identify and communicate economic and policy incentive mechanisms for greater Water Productivity

Method. Farmers frequently cite bigger scale policy and institutional environment as a major constraint. A rule for the local scale AIPs was not to get bogged down on issues that could not be resolved through dialogue with stakeholders within the AIP. Instead the AIP members communicated these bigger scale issues with government officials and project researchers into national and regional forums. In other words, the project itself became the link between the local AIPs and those larger scales of governance institutions in Mozambique, Tanzania and Zimbabwe. In Mozambique project partner the National Irrigation Institute was able to directly take up lessons from the research. In Tanzania, regular engagement with the Iringa District Council and National Irrigation Commission

facilitated uptake of innovations, while in Zimbabwe work with AGRITEX and the nation Irrigation Working Group enabled change.

At the regional scale, annual meetings and independent review were held that in identified policy reform opportunities across countries. A number of options for supplying policy relevant information into key regional processes *(e.g. NEPAD / CAADP)* that were developed on a flexible basis over the four years. A key opportunity was the participation in the project of FANRPAN, a multi-stakeholder, multi-national organisation that represents African national governments on agriculture and whose future events in those countries are an opportunity to engage political leaders in the region, for instance, through FANRPAN's national and regional multi-stakeholder policy dialogues.

Institutions involved

In Australia, The Australian National University (ANU) led the research work in the areas of effective water governance institutions, understanding the value of water and trade-offs across water users, between water users and the environment, innovation platforms and policy.

CSIRO Land and Water led the bio-physical agriculture and water productivity and learning components of this project.

The University of South Australia led the socioeconomic analysis and water economics research.

In Mozambique, the National Irrigation Institute is the government agency responsible for the development and management of irrigation in the country led the research.

In Tanzania, the Ardhi is the national university specialising in land and natural resource planning. They led the Tanzania research. Additionally support was provided from Sokoine, the national agricultural university. Both universities are intimately linked to government programs.

In Zimbabwe, ICRISAT is a leading agricultural research organisation and a centre of excellence on AIPs. They led the Zimbabwe research in collaboration with national institutions. Additionally they undertook key capacity building and mentoring of the AIP facilitators Tanzania and Mozambique, supported by ANU.

Based in South Africa, FANRPAN is constituted by member national governments across Africa. FANRPAN is an expert-based, non-governmental organisation that is endorsed by and has access to regional institutions. FANRPAN contributed expertise in food security, poverty reduction and gender equity implications of agricultural policies to this project.

The University of Pretoria is among Africa's premier research institutions on agricultural productivity. Their expertise complemented that of CSIRO and they provided a base in a hub city in Africa for key project activities, such as testing and calibrating equipment for water and solutes where this is not possible in country.

6 Achievements against activities and outputs/milestones

The following tables are based on Table 5.2 from the updated project proposal (1st October 2014).

No.	Objective & activity	Outputs / milestones	Target date
0	**Implementation activities**		
0.1	Establishment project institutions and hold initial workshop.	Sub-contracts agreed. Staff appointed. Project collaborators agree on the means to implement the work.	Aug 2013
Contracting. All eight partner sub-contracts were finalised and in operation soon after the project start in 2013, with finances being transferred and technical and financial reports being received. However, the ninth agreement with CSIRO was not finalised until early 2014. In October 2014 an updated proposal, incorporating additional capacity building and socio-economic surveys was approved by ACIAR. Sub-contracts were issued and signed by the partners involved and are in operation, with finances being transferred and activities underway. **Finance.** The financial arrangements generally proceeded well including the complex disbursement arrangement between FANRPAN and the countries. However, the devaluing of the Australian dollar against the US dollar; staff changes in various organisations; delays in invoicing and mistakes in processing caused challenges on various occasions, which were all resolved. **Staff.** When the project started the teams secured all their required staff quickly. But with a project covering several countries and multiple partners, inevitably a number of staff changes have occurred. Each organisation has been able to ensure a smooth transition from an outgoing staff member to a new researcher. The project totals 16.8 equivalent full time (EFTs) staff, of which 7.2 EFTs are in-kind. The project staff are listed in Table 5.3.1 in the updated proposal of 15th April 2014. **Inception workshop – Maputo.** The project launch and inception workshop was held from the 19th–22nd of August, 2013 in Maputo, Mozambique. This was the first meeting where the full project team met and discussed the project background, methodology, challenges and implementation. **Planning workshop – Pretoria.** On 10-11th of December 2013, a project planning meeting was held at the University of Pretoria, South Africa. Representatives from each partner organisation attended or participated via Skype. The meeting reviewed and finalised milestones, determined baseline situation data collection and initial indicators, reviewed and harmonised partner organisation plans, especially those for country site work; and agreed on reporting templates.			
0.2	Review and confirm irrigation scheme case studies.	Nine candidate irrigation areas assessed and sites selected for further research.	Dec 2013
Site selection: In 2013, twelve potential irrigation schemes were assessed as potential research sites – six in Zimbabwe, four in Tanzania and two in Mozambique. Site selection was discussed during the inception meeting in Maputo; and two sites were selected in each country (six sites in total). The criteria used included: smallholder irrigation; medium scale of the scheme; functionality of scheme infrastructure; diversity of crops; interest from local stakeholders; accessibility for researchers. The six irrigation schemes selected are: in Mozambique, 25 de Setembro and Khanimambo; in Tanzania, Kiwere and Magozi, and in Zimbabwe, Silalatshani and Mkoba (see Figure 2).			
0.3	Annual review.	Independent review advises project collaborators and ACIAR on enhancements required.	Each June

No.	Objective & activity	Outputs / milestones	Target date

Review advisors. The draft annual reports in 2014 and 2015 were reviewed by Professor Quentin Grafton, Dr Lindiwe Sibanda and Professor John Annandale.

Annual review meeting. We have held annual review meetings during which almost the whole team has attended, plus respective host country stakeholders from government. These have been used both as learning and planning exercises. As we have reviewed progress collectively and considered lessons both in the meetings and during sites visits and then identified any necessary adaptations required for the forthcoming year. The initial one was held in Iringa, Tanzania from 3rd-6th June 2014. The second was held in Bulawayo, Zimbabwe from 8th-12th June, 2015. The third was held in early August, 2016 Maputo, Mozambique.

Mid-term review. In April 2016, an external review of the project was undertaken (de Lange & Ogutu 2016). It was concluded that the research has enabled smallholder farmers and related stakeholders "to achieve success in a traditionally difficult sector, which is also currently a top priority for African governments and international donors". A key achievement has been that, in almost all the sites, these improved yields, profits and problem-solving were achieved before infrastructure investments were made, thereby strengthening the likely benefit and sustainability of future infrastructure investments. This provides credible proof of reduced risk, which should boost investor confidence. This success is intuitively attributed to the effective combination of two mutually strengthening factors (TAIP): 1) the introduction of on-farm self-monitoring tools has given farmers a positive expectation that they can consistently achieve better yields and profitability, thereby intensifying their need for better markets and their capacity for new crops and practices. 2) Simultaneously, the AIPs have facilitated a shared "five-year vision" among a wide range of stakeholders who stand to benefit from successful smallholder irrigation. The AIPs have been valuable in building relationships and identifying and systematically addressing the "current most pressing problem(s)" specific to its participants.

Objective 1: To evaluate whether agricultural innovation platforms based on existing community organisations can identify and overcome institutional and market barriers to greater water productivity.

No.	Activity	Outputs/ Milestones	Completion date
1.1	Establish AIP facilitation capacity.	Capacity to facilitate AIPs is established in each country.	By Dec 2013

AIP training. After facilitating the inception workshop, consultants PICOTEAM were due to work to build a common understanding and capacity to conduct AIPs among the in-country collaborators and facilitators through a series of workshops. However, subsequent discussions highlighted a difference in expectations, and after agreement from ACIAR, ICRISAT was engaged as an alternative capacity building partner given their extensive AIP experience. These negotiations resulted in delays in holding the initial training workshop.

On the 17th to 21st February 2014, 22 in-country collaborators and facilitators attended a workshop on Agriculture Innovation Platform & Farmers Soil & Moisture Monitoring Tool Kits which was held at ICRISAT in Bulawayo. The workshop trained facilitators from the three countries. Each team developed action plans for the first (Tanzania and Mozambique) or next workshops (Zimbabwe). The report of this training session is available on request.

AIP Mentoring: Dr Martin Moyo, ICRISAT, attended and supported the first AIP workshop held in Tanzania from the 20th–21st of March 2014. In Mozambique, ICRISAT provided contributions to the agenda of the first workshops, which were held from the 22nd–23rd of April 2014; however, no representative from ICRISAT was able to attend due to an agenda clash. Since then ICRISAT, has continued to provide mentoring to the facilitators and AIP meetings held in Tanzania and Mozambique.

1.2	AIP baseline assessments.	AIPs are established.	By June 2014

From late 2013 and into 2014 initial AIP workshops were held in all three countries, following a similar process: the stakeholders were encouraged to go through a process of jointly developing an understanding of the current situation; then developing a shared vision; then identifying how to get to the vision by exploring the problems, root causes and opportunities; out of which initial activities were identified; and often small groups were formed to address activities outside the formal AIP meetings. Most of the AIP activities then occurred outside (in between) the formal AIP meetings. Subsequent AIP meetings occurred in all countries, and were used to report back, review progress and identify the next set of actions. The following are summary updates from each country:

Mozambique - The first AIP meetings were held on the 22nd and 23rd of April 2014 for 25 de Setembro Cooperative and Khanimambo, and were attended by 55 stakeholders (including farmer producers, input suppliers, financial institutions, buyers, and government) and 42 stakeholders (including farmer producers, input suppliers and government) stakeholders respectively. Action plans were developed to guide interventions.

The second, AIP meeting combined stakeholders from both sites was held in October 2014, as several stakeholders were similar, and also to enable lesson sharing between sites. Infrastructure repairs were identified as the main issue to address as both schemes were inoperative with broken pumps and canals. Repairs started at 25 de Setembro, in mid-2015 and late 2015 at Khanimambo. Poor market access and low prices are major barriers, and work to identify more profitable crops and production schedules is underway. To access micro-finance farmers need identity cards, which have now been issued.

In November 2015, an AIP meeting was held just for Khanimambo with 19 participants (10 female and 9 male). The main actions agreed were to: build the capacity of their Association; open an Association saving bank account for infrastructure maintenance and repairs, develop a mechanism for the farmers to pay fees on a regular basis towards scheme operations; address under-utilised plots and land tenure issues; and build capacity to rehabilitate the entire 16 ha of the scheme. A similar meeting was held with the 25 de Setembro following infrastructure repairs.

No.	Activity	Outputs/ Milestones	Completion date

Tanzania – The first AIP meeting for Magozi and Kiwere was held as a combined meeting from the 20th-21st of March 2014 in Iringa and involved more than 50 stakeholders. Participants divided into groups of farmers from Kiwere and Magozi, technical staff from government institutions, representatives from agricultural training and research institutions and representatives from NGOs and input suppliers/traders identified challenges in the two schemes. Challenges identified at the schemes included: unreliable water delivery to the tail end of canals, agronomy, inputs, markets and technology. The causes of these problems, potential remedies and opportunities for change were discussed. The meeting also developed initial visions for the two schemes.

A second AIP meeting was held in July 2014 with both schemes further refined scheme visions and assessed their agricultural value chains in order to prioritize challenges to be addressed and identify stakeholders to be involved. The meeting was attended by about 60 participants representing farmers from Magozi and Kiwere, Iringa District Council, input suppliers and crop produce buyers, Iringa District Council, Iringa Region Secretariat, Zonal Irrigation Office, Rural Micro, Small & Medium Enterprise programme commonly known as Muunganisho wa Ujasiramali Vijijini (MUVI) Programme, Rural Urban Development Initiatives (RUDI), Irrigation and Technical Services, Ministry of Agriculture, Food Security and Cooperatives (MAFC) and researchers.

In 2015, two further AIP meetings were held. The first was held over three days with the first day focused on Magozi and the last day on Kiwere, with joint issues discussed on the middle day. The second meeting focused on developing the business plan for Magozi. These meetings involved small groups of farmers and key stakeholders for a number of priority issues arising from the first two meetings, which included: soil fertility management innovations based on soil sample analysis results, facilitating linkages to tomato processors and input providers in Kiwere, fencing out livestock and use of residual moisture after rice production at Magozi, training farmers on good agronomic practices in both schemes and preparation of the business plan for Magozi.

In early 2016 (March), an appointed committee by the September 2016 AIP met to finalise the preparation for business plan for Magozi, The committee drew representative from the research project, Iringa District Council, National Irrigation Commission and Farmers from Magozi scheme. During this meeting, the business plan was finalised and circulated to key stakeholders including the farmers themselves for final comments and inputs.

As part of AIP, farmers from Magozi conducted a study tour to Igomelo Irrigation scheme and Igurusi modern market and rice processing and storage facilities in Mbarali District from 20th to 22 July 2016. The farmers were accompanied by the project field research officer, Agriculture Officer from Iringa District Council, Agriculture Officer from National Irrigation Commission, Mbeya Zone and scheme extension officer. The farmers learned how the Igomelo irrigators' organisation implement their activities in the scheme. They also learned how to manage rice storage and processing facilities from Igurusi Agricultural Marketing Cooperative Societies. As result of the exposure and learning, the farmers developed an action plan of the scheme for the period of September 2016 - December 2017. They also initiated review of their irrigator's organisations (IO) constitution and bylaws. Initiation of the review followed their recognition that inadequate rules were one of the obstacles towards their success. A similar visit was also organised for Kiwere farmers in November 2016 who visited the Igomelo scheme. After the visit the farmers also initiated review of their constitution to improve the scheme management.

Overall AIP meeting participation has ranged from 26-49 participants, 68% of whom were farmers. Women farmers' representation from Magozi on average was 34% and 41% from Kiwere.

No.	Activity	Outputs/ Milestones	Completion date

Zimbabwe - After the Maputo project inception meeting, initial scoping visits were made to review and confirm the two selected irrigation schemes – Silalatshani scheme in Insiza District and Mkoba scheme in Gweru District - as research sites. The visits included engagement with the local communities and relevant authorities, and assessments of infrastructure, crops grown and challenges facing the farmers. During November, 2013, a consultative stakeholder process identified the key players involved in the selected schemes. The ICRISAT team then facilitated two workshops in November; one in Gweru for the Mkoba Irrigation Scheme (held on 11th-12th November 2013) and another in Filabusi, for the Silalatshani Irrigation Scheme (held on 18th-19th November 2013) to form AIPs. These workshops also served as means of assessing existing knowledge gaps within the scheme as well as additional stakeholders who could be invited to be part of the consultative stakeholder forum. Stakeholders who attended the meeting identified the huge water bill from ZINWA of more than US$280,000 at Silalatshani irrigation scheme as a major issue that had to be addressed. A working group including ZINWA was formed to address this issue, eventually reaching agreement to reduce the debt to US$80,000 to be paid over a year. AGRITEX has since liaised with ZINWA and opened up new water billing accounts for the different sections of Silalatshani irrigation scheme (but the farmers continued paying the old recalculated bill that had accumulated). This had made the administration of the different sections easier, as there is more co-operation from the sectional farmers than from the whole scheme. As of December 2016, all sections were up to date with their payments of the new bills. Further, ZINWA is now only charging water from the night storage dams as there were issues related to water losses during conveyance from the Silalabuhwa dam 12 km from the irrigation scheme)

Stakeholders at the Zimbabwe meeting in Gweru for the Mkoba Irrigation Scheme, held on 11th-12th November 2013 prioritised the following issues: 1. Introduction of high yielding seed varieties; 2. Use of soil fertility management technologies; 3. Irrigation water management (introduction on-farm water conservation techniques); 4. Catchment area management to reduce erosion; 5.Irrigation scheme modernisation (i.e. introduction of more efficient systems such as drip systems) 6.Empowering the Irrigation Management Committees (IMCs) including through legal registration; 7.Introduction of post-harvest technologies, including value addition, refrigeration and preservation. The capacity of the extension services and needs for new knowledge and technologies were also assessed.

A second AIP workshop was held in Mkoba, Gweru from the 29th-30th of April 2014, and at Silalatshani on 14th May 2014. The second Mkoba AIP had 20 male participants and 8 female participants (total of 28 participants).The second Silalatshani AIP meeting was well attended, with 13 female participants and 38 male participants (51 participants in total). Further meetings were held in 2015 to address key issues and opportunities, namely: subsistence versus commercial agricultural production, market access, land tenure, infrastructure ownership and scheme operations, and access to credit.

In Zimbabwe, two more AIP workshops were held; one at Mkoba (which was held on the on the 21st of September 2016), and the other at Silalatshani (which was held on the 5th of October 2016). The Silalatshani AIP meeting was attended by a total of 36 participants with 24 being males and 12 females & the one at Mkoba was attended by 35 participants i.e. 15 males and 20 females. These meetings were used as a way of reviewing the project (2013-2016) and following up on the findings of the last AIP meetings that were held in 2014. The main objectives of the AIP meetings were;

1. To share the project successes and failures and explore ways of enhancing the activities;
2. To develop a work plan for project implementation in 2016-17, including developing working arrangements between the stakeholders with clear roles and responsibilities.

Due to the recommendations from the innovation platform meetings that were held in the reporting period, the team also conducted some training workshops for the farmers and extension staff at both Mkoba and Silalatshani schemes on Objective 2 (on water and solute monitoring systems as an entry point for enhancing agricultural productivity). The AIP meeting reports are available on request.

No.	Activity	Outputs/ Milestones	Completion date
1.3	Innovations for change.	New knowledge and technologies are introduced.	From Jan 2014

New knowledge and technologies identified as needed during AIP process have been introduced.

Mozambique - In 2014, at 25 de Setembro identified land preparation and market transport issues, Through the AIP process synergies developed between the Ministry of Agriculture and Food Security and Japan International Cooperation Agency (JICA), and a new tractor with implements and 2 ton truck were secured for the scheme. The scheme farmers then prioritised as their entry point to engaging with the project the replacement of their pump, lining canals and levelling plots. At the Khanimambo irrigation scheme they also prioritised pump replacement and pipeline repairs. INIR secured US$6,000 and issued tenders to undertake this work in the second half of 2015. Meanwhile, the focus of the AIP process is now on capacity building of farmer associations, addressing land tenure issues, enabling access to credit and assessing agricultural markets.

Tanzania – At both schemes, work has focussed on improving plot and irrigation scheme management, including better practices for use of fertiliser, pesticides and herbicides through training and demonstration in the irrigated plots. At Kiwere, the use of Chameleon and WFDs has resulted in changes to optimize soil moisture and nutrient use for crops. In 2015-16, drains were built along irrigated plots and farm yard manure applied to help control salinity. In Magozi, a seasonal calendar for rice irrigation was adopted. Through the AIP meetings, the scheme has been linked to a Japanese funded Policy and Human Resources Development program of the Tanzanian Government, who have provided six combine harvesters. The IO used their AIP experience to develop a business plan to sustain the harvester hire service through user fees. A rice-milling machine with accessories for labelling and packaging to different weights was supplied in 2016. In order to increase the marketability of their rice during the 2014/15 season, farmers who were growing six different varieties of rice agreed to grow only the two traditional varieties with highest market demand, *faya dume* and *alfa mwanza*. In the 2015/16 season farmers were trained how to plant an improved rice variety (SARO 5TXD) under good agronomic practices and fertilizer management using demonstration plots.

No.	Activity	Outputs/ Milestones	Completion date

Zimbabwe – The AIP process (in the case of Silalatshani) has brought stakeholders together to a common understanding that land ownership was a major issue. One of the main issues that came out of the second Silalatshani AIP meeting was that there were a sizeable number of absentee landowners and irrigators who were not utilizing their land. AGRITEX indicated that the scheme was supposed to have 849 plot holders, but their registers indicated less than 300 landowners or users. This was a cause of concern that made the AIP meeting to resolve, through the district leadership (District Administrator (DA), Chief, Rural District Council and AGRITEX) to deal with the matter. The district leadership effectively suggested conducting a plot ownership audit. The project team had initially felt these issues might have been difficult to solve, however there are strong indications that these policy issues are being addressed, as such these can be viewed as project and AIP achievements. The DA and the local Chief have since held two meetings with the irrigators, discussing absentee landowners and trying to map a way forward. The project does acknowledge that dealing with land tenure issues is complex in Zimbabwe, but by starting the process to address some of the linked tenure issues; it could well have considerable economic and social impacts.

Poor soil fertility was one of the major technical constraints identified at the schemes and soil fertility management technologies have been introduced. Forty experiential farmer demonstration plots have been established at the schemes as maize paired plots highlighting the benefits of improved technologies, including optimum fertilizer application, manure use, timely management operations and the use of soil moisture monitoring devices-the WFD and the Chameleon. During the experiential demonstrations, it was observed that in the first 3-4 weeks of maize crop growth that there was no need to irrigate deeply to the 40 cm zone as the root zone was still shallow. Additionally, mulching, and conservation agriculture have been introduced in Mkoba. Green maize is being trialled for the fresh food market. At Silalatshani, the AIP work resulted in the recalculation (see 3.3.1) of the farmer's debt to ZINWA, saving US$200,000; and discussion has commenced with the District Authority on the ownership of unused irrigation plots. At both Mkoba and Silalatshani, the irrigators have agreed to work on irrigation infrastructure maintenance. The irrigators are now involved in maintaining the irrigation infrastructure, in particular: the dam wall (in the case of Mkoba- cutting trees and making sure there are no leakages); canal maintenance; and fencing to avoid livestock straying into the scheme and consuming farmers' crops.

In Zimbabwe, the AIP process has continued to evolve. Capacity building of AGRITEX and farmers has enhanced their negotiation skills so they are gaining better access to markets, with some commercial agreements made without the direct intervention of ICRISAT. A strong partnership with a local NGO, the Bulawayo Project Centre (BPC), has been established to develop links to city markets.

No.	Activity	Outputs/ Milestones	Completion date
1.4	Document resulting learning.	Resulting changes to agronomic and socio-economic documented.	By Jun and Dec of each year from 2014

The project started documentation started via workshop and annual meeting reports. An internal project learning blog was created but discontinued following limited use by project staff.

To facilitate ongoing analysis of learning and change a Before-After-Control-Impact (BACI) baseline farm level survey was undertaken. The survey records farm and household characteristics of irrigator households as well as perceptions on a number of issues related to the irrigation scheme and the community. The survey was led by Prof Henning Bjornlund (UniSA) with support from Sabine Homann-Kee Tui (ICRISAT), and undertaken by country research staff. UniSA conducted training in each country of enumerators and project staff. The surveys were conducted in mid-2014 in each country and results analysed. Further in-country data analysis capacity gaps were identified and addressed with training and mentoring from UniSA. In 2015, the reports were finalised, and the findings discussed in subsequent AIP and other stakeholder meetings. To address socio-economic capacity gaps and enable the comprehensive continuation of this work with semi-annual surveys and focus group discussions, an extension to existing proposal was submitted and approved by ACIAR in 2014. In 2015, the first two semi-annual survey and focus group discussions were completed in all six schemes to explore issues emerging from the analysis of the BACI survey. These short surveys were repeated in 2016, and an end of project final longer survey was conducted in March-April in 2017, was done to enable continued evaluation of changes and learning. During April and May further focus groups were conducted targeting two of the three identified disadvantaged groups, women and young farmers to assess project impact on these farmers and identify ways to better address their needs.

From 2015 to 2016, we have synthesised the knowledge gained by the first two years of the project into nine research papers published as an open access special issue of the *International Journal of Water Resources Development* (IJWRD; available on request). These papers assess the situation in each of the three countries, as well as with respect to inequality within schemes, agricultural extension, smallholder irrigation, AIPs, farmer learning on soil and water management, and national irrigation policies. These papers synthesise the information from project surveys and other reports (for further details see section 3.4). The special issue was officially launched during two sessions held at the World Water Congress in Cancun, Mexico in May 2017

The project has assisted five post-graduate students. From Australia, a master's student (Justin Rhodes) has completed research on agricultural extension and a PhD scholar (Ana Manero) has submitted her thesis on inequality within irrigation schemes. A Mozambican former project staff member (André Machava) has commenced an Australia Awards master's scholarship at UniSA, Adelaide. A Tanzanian extension officer, Urban Kalimba who has been closely involved in the project is now undertaking an MSc at Charles Stuart University, Australia. An Ethiopian PhD scholar (Michael Assefa) researching cognate irrigation scheme management is receiving technical support from project staff. From the University of Zimbabwe, Josephine Ngirazi an MSc student, has conducted her research on the Mkoba irrigation scheme. These scholars extend the learning and benefits derived from the project.

Objective 2: To develop, test and deploy water monitoring systems at each site as an entry point for enhancing agricultural productivity …

No.	Activity	Outputs/ Milestones	Completion date
2.1	Establish baseline conditions.	Baseline water, solute and agricultural conditions documented.	By Sept 2014

Establishment of baseline water, solute and agricultural conditions occurred during the initial phase of the project.

Site profile baseline: Many of the baseline conditions at the six schemes have been captured in the baseline survey reports. Country specific reports were produced and summarised in the UniSA report available on http://fennerschool.anu.edu.au/research/projects/africa-irrigation-and-water-project-increasing-irrigation-water-productivity-5.

Water and solute conditions: In February 2014 a water and solute training session was undertaken in Bulawayo with the three country teams. Baseline water, solute and soil conditions were established in 2013-14 in Zimbabwe. In Tanzania and Mozambique the baseline, conditions were established in 2014-15. The soil analysis results from all six-project schemes identified yield-limiting conditions, showing low soil fertility and in particular, low phosphorus and nitrogen levels. There was excess water available in the fields in all of the schemes.

No.	Activity	Outputs/ Milestones	Completion date
2.2	Water and solute monitoring.	Time series data on water, solutes, crop yields and market returns is collected.	Ongoing from Jan 2014

Collection of weekly soil water and solute data has been ongoing (baring gaps for fallow and non-cropping periods or equipment breakdown) across five schemes in the three countries. It has is not been practical to use the monitoring tools (WFD and Chameleon) in Magozi, Tanzania because of the flooded rice cropping system practised in that scheme.

Equipment making - From August 2013 the manufacture and testing of the CSIRO designed soil water monitoring equipment began at the University of Pretoria. Laboratory testing of Chameleon sensors involves embedding sensors and tensiometers in a test rig of wet diatomaceous earth and taking readings as the test rig dries out. Sensor performance is analysed and poor-performing sensors are discarded/remade. To date over 3,500 sensors have been made which have been distributed to Africa, Asia and other places. All materials and human capacity for sensor making have been successfully sourced in South Africa. At CSIRO, a redesign of the Chameleon package is at an advanced stage.

Field testing of sensors – In 2013-14 field tests were conducted of the performance of Chameleon sensors against other moisture measuring tools. Tensiometers and 18 Chameleon sensors were installed in a Swiss chard trial at depths of 25 and 50 cm. The trial was located at the Hatfield Experimental Farm of the University of Pretoria. Readings from Chameleon sensors were calibrated with tensiometer readings.

Capacity building - Country researchers were trained in equipment installation and use in February 2014 in Bulawayo; and more detailed mentoring with the country researchers on equipment installation and data collection then occurred in each country. Additionally with the farmers, this has been iterative and ongoing process to build their capacity to record, interpret the data and adapt their management regimes.

Distribution – Limited numbers of tools were distributed in December 2013 to country teams to enhance their familiarity with the equipment. Following feedback at the February 2014 training session, the required water and solute monitoring equipment was distributed in 2014 to all three countries, including: pocket EC meters, nitrate test strips, WFD, Chameleon sensors and readers. Distribution of required equipment has continued since. Excessive transport and importation fees remain a major barrier to scaling up use of the tools in the three countries, and has required project staff to transport equipment in their personal luggage to effect timely delivery at a reasonable price

No.	Activity	Outputs/ Milestones	Completion date
Mozambique - The soil and water monitoring devices WFD and Chameleon were installed in 20 farmer plots in 25 de Setembro and 10 farmer plots in Khanimambo. One farmer in each scheme was trained in the use of and management of the Chameleon device to help others take readings. Data recording has taken place on a weekly basis, with the project team conducting nitrate and EC readings and discussing the results with farmers. However, at both schemes data collection has been interrupted by stoppages in farming activities due to flooding and infrastructure failures. Repairs to the infrastructure in 2015-16, enabled recording to resume. While scheme construction was under way, five key farmers were selected to start using the tool and added five more for each season for those who showed interest in the tools, by the end of 2016 20 farmers were using the tools. Currently 20 farmers have WFD and Chameleons installed in their plots and the reading are been taken three times a week. **Tanzania –** The equipment was not installed in Magozi rice growing scheme, however it was installed in Kiwere and farmers were trained in data collection. From August 2014 soil moisture and solute data was collected and then discussed with the farmers. The plots installed with Chameleons and WFD are entirely managed by the farmers. Not all of the 20 farmers have resources (capital) for farming when the cropping season starts, resulting in gaps in recorded soil moisture and nutrients. Farm inputs, crop yields and market returns since the 2013/14 cropping season up to June 2017 have been collected and analysed from the two schemes. **Zimbabwe –** 20 WFD and Chameleons were installed from January 2014 on irrigator plots at each of the Mkoba and Silalatshani schemes. Farmer training accompanied installation. Dedicated, trained farmers, assisted by AGRITEX and Department of Irrigation (DoIRR) staff, are collecting data every week. Monitoring of solutes and moisture is ongoing. These tools have assisted in changing the farmers' mindsets on when and how long to irrigate.			
2.3	Improved management.	New management techniques are implemented.	Ongoing from Jan 2014
A number of new management techniques have been identified and implemented through the on-site monitoring and also the soil analysis. **Mozambique –** A number of the farmers who have WFD and Chameleon sensors in their plots report that they reduced the frequency of irrigation. Previously they visually assessed soil moisture and irrigated once a week. These tools have developed the farmers' understanding that despite the soil looking dry in the upper layers that there was still moisture in the root zone and thus there was no need to irrigate. However, at both schemes floods and infrastructure failures in 2015 interrupted data collection, interpretation and farmer learning.			

No.	Activity	Outputs/ Milestones	Completion date
Tanzania – The 20 farmers in Kiwere using Chameleon and WFDs report reducing their frequency of irrigation by more than half. Other farmers at the scheme are following the example of those with equipment and watering less frequently, and as a result, farmers with tail-end plots report water supplies that are more reliable. At Magozi, these tools have not been installed because rice production involves saturating the fields with water, so a local project partner, RUDI, introduced an irrigation calendar in January 2015. Unfortunately, the farmers did not adopt it in 2015 because RUDI introduced the initiative after the farmers had started rice-farming activities. In 2016, the scheme was flooded several times in January and February, resulting in damage to irrigation canals. In June 2015, three plots were established in Magozi to trial cowpea to utilise residual soil moisture after harvesting rice. Although the cowpea germination rate was very good (80-90%), all the plots were destroyed by the cattle which are allowed to graze in the scheme. The Irrigation Act of 2013 prohibits grazing of crop residues within an irrigation scheme and it is a major source of conflict. At least two farmers in Magozi have adopted the recommended fertilizer application during the 2015/16 season following the soil analysis and the outcome indicated farmers realised crop yield of about 9tons/ha compared to 6tons/ha under traditional practices (traditional rice variety without fertilizer application). To address some of the soil limiting conditions, discussions have been held with farmers and stakeholders at both schemes; the project has facilitated training on pest and soil fertility management in Kiwere, and trial plots comparing with and without fertiliser application have been established in Magozi.			
Zimbabwe – Farmers using the sensors have reported watering their plots less frequently. Furthermore, 40 (20 apiece at the 2 schemes) soil fertility (use of inorganic and organic fertilisers) management demonstration plots have been set up for experiential learning. In Mkoba, composting and conservation agriculture have been introduced. Further farmer trainings were held at both Silalatshani (a total of 12 participants attended i.e. 9 females and 3 males) and Mkoba irrigation schemes (a total of 17 participants attended i.e. 8 males and 9 females) on the 1st and 2nd of November 2016, respectively. These trainings had been requested for by the farmers and extension staff during the AIP Review meetings that were held in September and October 2016. The trainings mainly targeted the key personnel at the scheme i.e. the irrigation management committee of both schemes and the extension staff and the main objectives of the training were: • To enlighten lead farmers (or the IMCs) and AGRITEX staff on solute and moisture monitoring tools, agronomic aspects of irrigated crops and water conservation strategies in irrigation schemes • To highlight strategies that could be adopted by farmers in order to mitigate climate change and variability so as to ensure resilient			

No.	Activity	Outputs/ Milestones	Completion date
2.4	Change in resource conditions and economics.	Change in resource conditions and economics are documented.	Ongoing from Apr 2014
Data collection on changes in resource and economic conditions occurred with project staff regularly visiting the schemes to collect data, make observations and conduct formal and informal discussions with irrigators and their leaders; capturing overall changes in resource use conditions. Though collecting data on farm inputs, crop yields and market return continues to presented many challenges, for example, some crops are harvested over several weeks, e.g. tomatoes which creates issues when measuring yields. Further, the short survey and focus group discussions which were conducted semi-annually in each site from in January and July 2015 are capturing overall changes in resource use conditions, which are being analysed and documented. The short surveys have targeted 20 households from each scheme, selected from the initial survey sample, were used to explore issues emerging from the first survey. These are to be repeated in 2016, and a final survey in 2017. In Zimbabwe, based on information provided from the schemes by AGRITEX staff, gross margin analysis was undertaken of previously recommended agronomic practices. The analysis demonstrated that growing staple crops (maize, winter wheat) was uneconomic, leading to current work to identify crops that are more profitable: assessing garlic, groundnuts and stock feed. Similar gross margin analyses were been conducted in Tanzania and Mozambique. In Kiwere a gross margin analysis for 2014/2015, indicated that tomatoes are more profitable than eggplants or onions. However, in 2015 the majority of farmers planted green maize instead of tomatoes because tomato leaf-miner, *Tuta absoluta*, had seriously affected tomato production in the scheme and other parts of the district. In Magozi the analysis showed that in 2014/15 19 farmers out of 20 monitored farmers made profits in the range from US$ 116-5,100 from their rice crop. Only a single farmer made a loss, which was because the irrigation water was stopped when the rice was at flowering stage.			
2.5	Collate research results to support AIPs.	Options for enhancing resource conditions collated to inform AIPs.	Annually in Q2 each year
Interpretation of the water and solute data, and records of agronomic practices and crop yield of rice, maize etc., have been discussed with farmers in the AIPs. Additional information collected from six monthly focus group discussions and short surveys, is also being analysed and fed back through the AIPs.			

Objective 3: To identify and communicate economic and policy incentive mechanisms for greater water productivity

No.	Activity	Outputs/ Milestones	Completion date
3.1	Assess current water incentives and disincentives	Current economic and other incentives and disincentives for water use in irrigation are identified.	By Sept 2014 and again by Sept 2016

During the initial AIP meetings in all three countries, preliminary discussions were held on incentives and disincentives for water use in irrigation. The most significant discussions were in the Zimbabwe AIP meeting, where water and electricity supply issues emerged as a major concern as farmers expressed their dissatisfaction with the pricing policy of water. Secondary data sources, including the site situation reports and further AIP meetings have provided more data.

FANRPAN and ANU have drawn on this data on economic and other incentives and disincentives for water use in irrigation. The analysis highlights the need to improve the profitability and governance of smallholder irrigation in the three countries with greater: a) clarity of land tenures and water use rights; b) capacity building of irrigation farmer associations, and c) access to good quality farming inputs, equipment and markets through national regulatory reform. The analysis further suggests that currently the only incentives for farmers to conserve water are: a) the cost of energy where pumps are used, and b) where over-irrigation harms crop production, but this only influences water use where farmers have requisite knowledge. Once the tools have been used and watering frequency reduced, farmers report labour saved from skipped irrigations is a major incentive. See Mwamakamba et al., 2017.

Furthermore, FANRPAN through a partnership with WaterNet commissioned research to explore institutional issues in Zimbabwe. The research was conducted by a FANRPAN sponsored masters student as part of the Regional Masters Programme in Integrated Water Resources Management

FANRPAN commissioned an analysis of gender within the project. The analysis was designed to assess how gender issues have been incorporated within the project but most importantly, to assess whether there might be barriers hindering the equal or equitable participation of women and men in the project. A research paper on gender in decision making in the irrigation households is in review. Key findings are summarised below.

No.	Activity	Outputs/ Milestones	Completion date
3.2	National policy	Options identified from the project for national policy reforms are communicated to policy institutions.	Annually from 2014

FANRPAN - FANRPAN has reviewed the national irrigation policies from the three project countries. Key findings are documented in the policy paper. A partnership with the Water Policy Programme of the UK Overseas Development Institute (ODI) further assessed policy options and innovations to support irrigation development. Furthermore, based on feedback from project partners and FANRPAN's tracking of national irrigation policy environment the following has been noted:

Mozambique: Project partner INIR, based in part on experiences from the project, prepared the national regulation for irrigation associations (Lei de associações de regantes). Cabinet Council approved it in May 2015, but remains to be implemented by Ministers. INIR is using the project sites as two of ten pilot schemes for implementation of this legislation. Following the adoption of the new irrigation regulations, the irrigation management association own and are responsible for maintaining this infrastructure. As part of the regulations, business plans were prepared for each of the two schemes in the project in 2016 by the associations with support from INIR. Capacity building was conducted for the scheme farmers, and extension officers from the district level, and included:

- Helping the farmers to analyse the markets.
- Facilitating farmers to prepare their own business plans.
- Preparing a collective business plan for the schemes.
- Enabling the extension officers to assist the farmers with their planning.

Tanzania: Irrigation decision makers at national, regional and district levels consider the two irrigation schemes in Tanzania exemplary. As such, they form part of the Tanzania Government's focus to transition farmers from subsistence to business oriented and commercial production, through the 'Big Results Now' initiative. Through the initiative, they are receiving resources and scheme management capacity building. The Irrigation Commission is looking into the possibility of using the irrigated plot mapping of Kiwere and Magozi developed by the project for issuing of individual farmers with CCROs, that enable individual farmers to access credit from financial institutions. The Commission would like to scale up the mapping to other irrigation schemes.

Zimbabwe: Discussions with district and national agencies have started reforms related to agricultural water pricing and recording ownership of irrigation plots. Following engagement with senior departmental officials at a 2015 workshop (see 3.3 below), in 2016, with FANRPAN's support, a Zimbabwean masters student conducted research on "the influence of institutional arrangements on smallholder irrigation productivity"

No.	Activity	Outputs/ Milestones	Completion date
All countries. In 2016, Country teams with support from FANRPAN facilitated gender focus group discussions. The FDGs were conducted in response to recommendations from the Project Gender Analysis Report. The FDGs were designed to identify water related needs, preferences, constraints and risks that differ by gender and social group in the irrigation schemes the project is working on. These involved two focus group meetings at each scheme i.e. one FGD with women only, predominantly with female headed households; and a second FGD with male and females from male headed households. The three research areas for these FGDs included: i. Joint decision making analysis. ii. Gender analysis. iii. Generational equity analysis. Some of the core findings that were captured through these group discussions at the scheme included; • No or very little gender discrimination in irrigation technology and water access. • Decisions on water use at household and community is done liberally by men and women equally, Women are major water overseers at grassroots level, and have a cross cutting role on water management from household to community level. • Participants had difficulty thinking beyond crop irrigation and obvious domestic usages i.e. cooking, washing when considering various water uses.			
3.3	Engaging regional policy makers	Options identified from the project for regional policy reforms are communicated to policy institutions.	Annually from 2014
	FANRPAN embarked on the following activities aimed at communicating options for regional policy reforms: FANRPAN held a meeting on the 4th of March 2016 to brief Mr Ringson Chitsiko, Permanent Secretary of Zimbabwe's Agriculture, Mechanisation and Irrigation Development on the ACIAR project and the emerging policy recommendations (A similar briefing was held on the 16th of March 2017). Furthermore FANRPAN took advantage of the national Climate Smart Agriculture (CSA) policy dialogues in Tanzania (29 March 2016) and Zimbabwe (23-24 June 2016) to share evidence from the project of irrigation being one of the water-use efficiency technologies that is being promoted under CSA. Some 64 stakeholders who included senior officials of national governments, donor organizations, farmers' organizations, agri-business, development partner agencies and civil society organizations attended the Tanzania policy dialogue. Whilst the Zimbabwe policy dialogue was attended by 67 stakeholders including Mr Ringson Chitsiko who officiated the policy dialogue. On the 15th of June 2017, FANRPAN Ad Interim CEO, Dr Takavarasha met with the SADC Executive Secretary Dr Stergomena Lawrence Tax and her team and gave a brief on the project. A directive was given to Mr Bentry Chaura, Acting Director FANR SADC by the Executive Secretary to ensure that the SADC Water Unit works closely with FANRPAN to ensure that projects output feed into SADC processes.		

No.	Activity	Outputs/ Milestones	Completion date
	In July 2015, a workshop on "Sustainable Irrigation Development and Water Management for Food Security and Rural Livelihoods Improvement in a Changing Environment" was organized by ICRISAT in collaboration with the Ministry of Agriculture, Mechanization and Irrigation Development in Zimbabwe, and McGill University in Harare, Zimbabwe. Some 72 participants (60 male & 12 female) policy makers, researchers, and development partners attended the workshop, from the National Agricultural Research and Extension Systems and international development agencies in Zimbabwe including the Swedish Development Cooperation, UN Food and Agriculture Organisation, European Union, and ACIAR, who provided funding for the workshop. A project overview was presented by ANU, country examples and lessons were presented from Tanzania and Zimbabwe, and FANRPAN presented preliminary policy findings. The need for adopting an integrated approach that considers technical as well as socio-economic issues for irrigation development in Zimbabwe and the region was one of the key points that emerged at the workshop. The workshop highlighted the need for creating an enabling environment for successful irrigation development that included policies and institutional issues, and on linking the irrigation systems to markets so that farmers can make sound investments in irrigation. There was sharing of technical information as well as identifying the challenges and the opportunities primarily within knowledge systems. The workshop agreed that there is a need to develop a deeper understanding of the complex array of challenges and opportunities in smallholder irrigation systems. The findings would then guide the identification of strategies and interventions that could be put in place to address these challenges using a wider and inclusive value chain approach. Some key issues that could steer the research agenda in irrigation development include: • Setting up a framework for crop value chain analysis and building up a spectrum of crops to be part of a value chain that meets the household food needs, income, and for local and export markets. • Bringing in private investors who can provide capital and finance for infrastructure to enable storage of commodities to meet year-round food supply. • Leveraging the use of information technology in agriculture, as well as engaging youth and women. • Working on improvement of crop production through capacity building, promotion and up scaling of tools and technologies to assist farmers (embedded in the realities that are found in these irrigation schemes.		

7 Key results and discussion

Defining the problems

The research in the six irrigation schemes in Mozambique, Tanzania and Zimbabwe identified a range of barriers to more profitable and sustainable irrigation (de Sousa et al., 2017; Mdemu, Mziray, Bjornlund, & Kashaigili, 2016; Moyo, van Rooyen, Moyo, Chivenge, & Bjornlund, 2016). These include:

1) Institutional issues:
   a) Governments often require farmers to grow staple food crops that have low-value instead of more profitable cash crops;
   b) There is often a lack of clarity over whether the government or farmers are responsible for maintaining key pieces of infrastructure, like primary canals, and consequently the service they receive for paying water fees;
   c) There is a negative feedback cycle where farmers are unwilling to pay fees to irrigation associations when they often receive a poor service in terms of water supply, jeopardising the resources needed for irrigation scheme maintenance;
   d) Irrigation associations lack clear powers to make decisions and enforce scheme rules resulting in problems such as: stray cattle damaging infrastructure and crops, water theft, inequitable water distribution with schemes, lack of participation in maintenance work and low rates of payment of water fees;
   e) Administrative and judicial processes that on paper may address such problems (for instance, issuing certificates of occupation of land or prosecuting farmers who do not pay fees) are effectively out of reach of farmers. The government agencies responsible are usually located in major towns requiring extensive travel to access, charge fees and take time that the farmers cannot afford;
   f) The irrigator associations have been unable to ensure adequate water supply to all farmers and the resulting conflicts have eroded trust in collective actions, such as canal maintenance. A further consequence is lack of institutional trust or capacity to order agricultural inputs and transport services in bulk to lower costs, or to schedule crop production
2) Market related issues:
   a) There is limited information on prices of agricultural produce in major urban markets that would inform farmers decisions on what crops to grow to maximise returns across the season;
   b) Farmers have had no communication with buyers to ascertain the timing and quality desired in order to maximise the prices that they receive for their produce;
   c) Farmers are often the victims of supply of counterfeit or low quality seeds and fertilisers;
3) Production related issues:
   a) Water management is poor with over application of water leading to leaching out of nutrients and waterlogging.
   b) Farmers often lack control over water scheduling and thus do not have the flexibility to grow different crops;
   c) Plot holders lack tenure over their land limiting their ability to access finance or to acquire additional plots;

d) The authorities responsible for assigning plots to farmers often do not ensure that the land is farmed (for example, where the farmers have moved to cities as labourers), increasing the costs for remaining farmers (e.g. in canal maintenance and water payments) and diminishing the economies of scale for supporting agricultural businesses

Research results

Strengthening institutions

Strengthening institutions and improving the linkages between them are crucial for more efficient and sustainable irrigation systems. Confusion over the role and powers of the irrigation associations contributes to the lack of profitability and sustainability of the schemes, as highlighted in the case of Zimbabwe (Moyo et al. 2016). There the government owns and operates the headworks and the irrigators manage the infield works, but there is a lack of clarity over who owns, operates, maintains and pays for conveyance structures. While the legality and authority of the associations remains unclear, the loss of water, theft, limited fee collection and confusion over what these funds are used for, and lack of enforcement of rules, reduces maintenance of infrastructure and scheme productivity. In response to these issues, in Mozambique, new regulations seek to provide clarity on roles and responsibilities of associations (Mwamakamba et al., 2017).

Extension services were identified as the main source of information for the majority of irrigation farmers, and it was also found that those who use irrigation extension services were more likely to adopt hard technology innovations (Wheeler et al., 2016). However, in Mozambique, it was found that an improved extension service that helps identify cropping strategies better aligned with market demand would significantly improve irrigation profitability (de Sousa et al., 2017).

Markets

While the lack of maintenance and breakdown of irrigation infrastructure are readily visible in many schemes, we argue that they are a symptom of failed institutions illustrated by the barriers detailed here, reinforcing the need to invest in the capacities of local people. The baseline survey and AIPs suggested that the most critical barrier to more successful irrigated agriculture is market access (de Sousa at al. 2015; Moyo at al. 2015; Mziray & Mdemu 2015; van Rooyen at al. 2017).

Marketing of produce is uncoordinated at most irrigation schemes, but mobile telephone technologies were offering opportunities for timely dissemination of market information in Mozambique and Zimbabwe (de Sousa et al., 2017; Moyo et al., 2016). More generally, institutions are needed to provide the feedback mechanisms within agricultural value chains to allow irrigators to align their operations to market demands and improve viability of irrigation systems (Moyo et al., 2016).

The research in Mozambique and Zimbabwe found that major barriers to more profitable and sustainable irrigation were lack of market connections, poor infrastructure and soil fertility, as well as limited access to high quality farm inputs, farm implements and agricultural knowledge (de Sousa et al., 2017; Moyo et al., 2016). This resulted in low crop yields, food insecurity and often negative farm income. The research in Tanzania highlighted that lack of finance is a key barrier as it affects farmers' timely access to adequate supply of high quality agricultural inputs, machinery, and transport to profitable markets. However, it was also found that providing access to capital alone would not necessarily solve the problem as under current market arrangement farmers did not have the confidence to borrow money as it was uncertain whether they could sell the produce at a profitable price (Mdemu et al., 2016).

Income inequality

The diversity of irrigators within schemes was illustrated at the 25 Setembro irrigation scheme in Mozambique. There seven different irrigator types with different crop diversification strategies were distinguished, reflecting farmers' resource access (de Sousa et al., 2017). Most farmers in the scheme produced traditional food crops, and while there were opportunities for growing crops that are more profitable, few did this. Analysis of income disparities within the six smallholder irrigation schemes show large disparities. This indicates that inadvertently, nation-wide strategies may overlook high inequality at smaller scales (Manero, 2016). Consequently, development policies should be tailored to more specific areas of intervention, such as issuing official documents to farmers on their land use entitlements so that they can more readily access finance (Mdemu et al. 2016). Further, it was found that increasing earning from agriculture will not even out inequalities as families with more diverse, off farm income sources have the highest total income (Manero, 2016). This issue was clearly highlighted during end of project review visits. When asked how farmers used time saved through reduced irrigation, non-farming income generating activities featured frequently (e.g. producing mud bricks and baking buns).

Complex systems

The results from the cross-cutting thematic research in the areas of information, extension, farmer learning and engagement in the value chain point to a number of the potential interventions for more profitable and sustainable smallholder irrigation. The irrigation schemes displayed many characteristics of complex adaptive systems (Bjornlund et al., 2016; van Rooyen et al., 2017). This indicates the need for complementary interventions at different scales to promote greater profitability and sustainability, such as linking soil and water monitoring tools within the context of functioning markets, as it was done in this project using AIPs.

These results stress that first point of entry for reform are the 'soft systems', and that once the soft systems are fixed the hardware systems will be much easier to maintain, to facilitate more profitable and sustainable irrigation (Moyo et al., 2016). Agricultural innovation platforms were helpful at all schemes as they facilitated stakeholder interactions (beyond the traditional agricultural engineering group), enhanced relationships among them, and enabled information exchange and knowledge sharing throughout the system and associated value chains. Moreover, by discussing challenges and opportunities, and working together to improve the irrigation system towards a shared vision, innovative solutions were developed and tested (van Rooyen et al., 2017). The need to develop profitable markets was the clearest message. AIPs are facilitating the development of responsive learning systems, able to adapt and re-organize in response to information and change.

The combination of Tools plus Agricultural Innovation Platforms (TAIP) as positively synergistic interventions for reinvigorating failing and complex small holder irrigation schemes was a major finding from this project. In their independent review of the Increasing irrigation water productivity project, de Lange and Ogutu (2016) found that AIPs combined with soil moisture and nutrient measuring can substantially increase crop yields and incomes of farmers, and make irrigation schemes more self-sustaining. They noted that improved yields, profits and problem solving were achieved before infrastructure investments were made in Tanzania and Zimbabwe, thereby strengthening the likely benefit and sustainability of future infrastructure investments. They concluded that the project enabled smallholder farmers and related stakeholders to achieve success in a traditionally difficult sector, which is also currently a top priority for African governments and international donors.

Policy requirements

In terms of overarching policies, development of publicly owned smallholder irrigation schemes has erred in focussing on small plots producing staple food crops that are barely (if at all) profitable. Policy responses could include reforms to land tenure, strengthening farmer organisations and fostering market linkages to enable profitable irrigation (Mwamakamba et al., 2017). To gain from new investment in irrigation, without repeating past failures, it is critical to develop business models for small-scale irrigation schemes (Bjornlund et al., 2016).

Improving production through on farm water and nutrient monitoring

When small-holder irrigation farmers were provided with simple soil water and solute monitoring tools they learnt to change their management practices within a short time The farmers were able to keep the root zones wet enough to enable high crop yields. Apart from the two Mozambican schemes, Chameleon sensors showed blue (wet soil) over 70% of the time, and all sites showed red (dry soil) less than 20% of the time (Figure 3) (Stirzaker et al., 2017). The farm crop monitoring data was manually uploaded onto the VIA platform (www.via.farm), Appendix 1 contains a summary analysis of that data

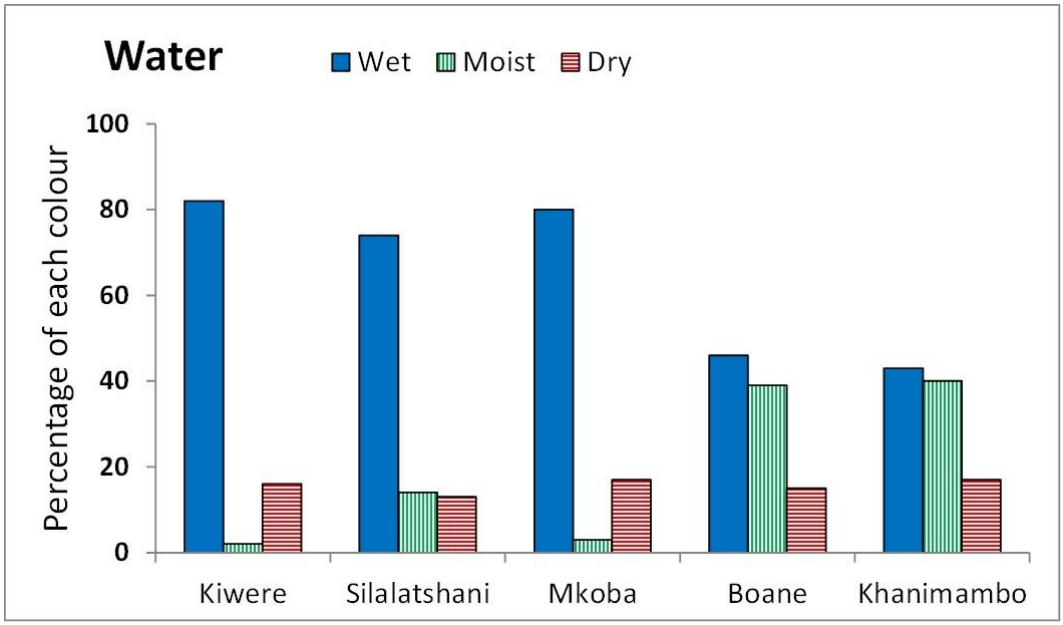


Figure 3. Soil water conditions at each scheme: the percentage of blue (wet), green (moist) and red (dry) colours reported on the Chameleon soil moisture sensors. (adapted from Stirzaker et al., 2017)

Soil nitrate levels were also adequate, at least at the start of the season. In most cases high yields were not obtained, probably because excess irrigation leached nutrients beyond the root zone. (Figure 4)

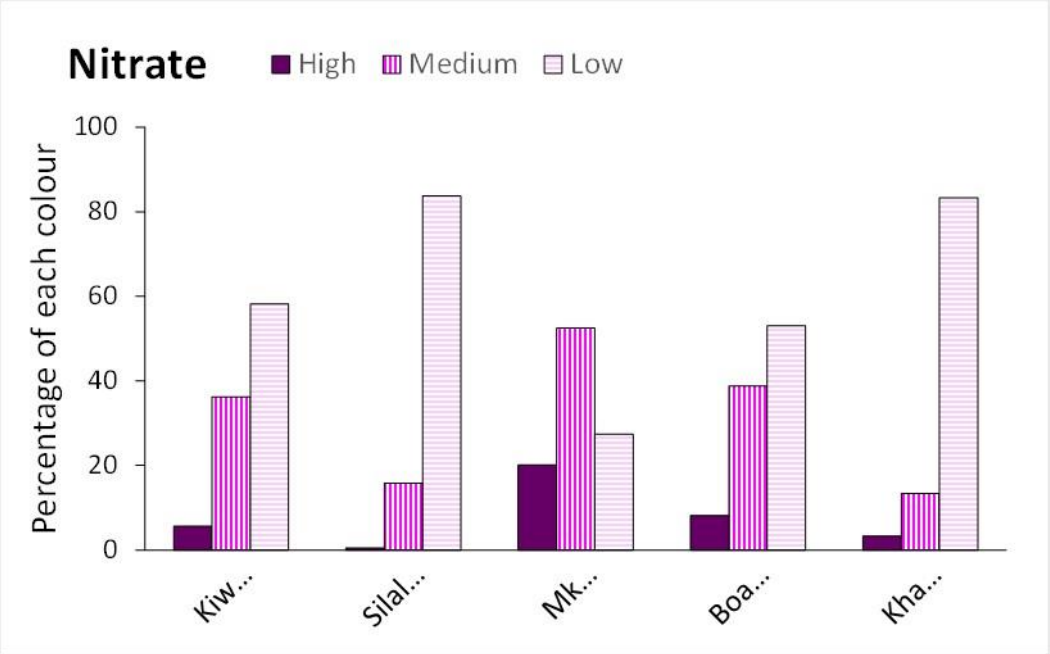


Figure 4. Soil nitrate concentrations at each scheme: the percentage of high, adequate and low nitrate colours reported from the FullStop wetting front detector samples, averaged over both depths. (Adapted from Stirzaker et al., 2017)

Farmers were able to understand and interpret the colour patterns from the Chameleon soil moisture sensors and the nitrate patterns from the FullStop wetting front detectors. In the Kiwere irrigation scheme, the farmers exploited the flexibility of their system and made major changes to their irrigation management. The farmers were most concerned about the rapid drop in soil nitrate levels early in the season. One farmer had started to skip scheduled irrigations and noticed that the new crop growth was greener and more luxuriant. The practice spread to the other farmers, and the concept of over-irrigation quickly became the common perception. At the start of the season, just under half the farmers irrigated twice per week, and the others three or four times per week. By the end of the season, most farmers irrigated once per week, and none irrigated more than twice per week. Given that this was the dry season, and assuming that each irrigation event applies a similar amount of water, reductions in water use could be estimated by the change in the number of irrigation events, as shown in Table 3.

Table 3: Change in number of irrigations (adapted from Stirzaker et al., 2017)

Change in number of irrigations per week	Percentage drop in irrigation	Number of farmers
3 to 2	33%	5
4 to 2	50%	9
2 to 1	50%	9
3 to 1	66%	3

These management changes spread to farmers outside the group directly involved in the project, and interest in monitoring also spread from farmers to extension workers and managers of irrigation schemes.

The cost of implementing this kind of farmer learning system is a small fraction of the capital cost of setting up irrigation schemes, and should be factored into the design of projects, rather than being added when schemes are starting to fail. (Stirzaker et al., 2017)

8 Impacts

8.1 Scientific impacts – now and in 5 years

Our project approach and preliminary results have been shared at conferences; however, it is too early to ascertain the extent of changes in scientific practices as a result of the project's findings.

A key output is the special issue of the *International Journal of Water Resources Development* (2017, 25(3): The Productivity and Profitability of small scale communal irrigation system in south-eastern Africa. Edited by Bjornlund and Pittock, the special issue has now been published for open access and was officially launched at the World Water Congress in Cancun, May 2017. The editor of the journal report that it has already attracted significant attention and she reports a surge in the submission of papers on small scale irrigation in developing countries. The most important research findings will be better communicated in the next set of papers emerging from this project in coming months that will include more quantified assessments based on the end of project survey and over a year's extra research experience.

The project has made a number of significant findings that we expect will change research in irrigated agriculture in the coming five years as this knowledge is further communicated and the second phase of the project focusses on scaling out and up. The findings are that:

a) When farmers have access to simple tools that they will learn themselves and rapidly change their agronomic practices;
b) The main value of more efficient irrigation water use in situations, where water is not pumped and has an energy cost, is in saving labour that can then be devoted to other livelihood activities;
c) AIPs enable farming communities to develop their own institutional capacities to identify and prioritise their own problems and opportunities, and organise positive change;
d) Irrigation schemes are complex systems which require multiple, complementary interventions to 'reboot' to a more sustainable state. In this project, the combination of Tools and Agricultural Innovation Platforms (TAIP) has provided the necessary interventions to do this.

We anticipate that these findings will help shift the focus of research into sustainable irrigation away from a focus on infrastructure and investment economics towards a more holistic approach with a significant emphasis on better governance institutions.

8.2 Capacity impacts – now and in 5 years

The capacity building activities are described in section 4. Indications of how participants in capacity building activities in this project are using this knowledge outside the scope of the project include:

Self-perpetuating AIP innovation capacity: The objective with AIPs is to see two self-perpetuating changes, namely:

a) Community innovation capacity - AIPs established and aided by researchers to address one problem or opportunity instil skills and experience that the community independently applies to address another problem or opportunity.

At half of the schemes involved in the research the irrigation farmers have demonstrated a new capacity independent of the research team to agree, plan and implement activities that are required for their farming systems to thrive. At Magozi the business plan developed through the AIP has been used by the community to secure the funding needed to establish a communal harvester machinery hire business, build a rice mill and a warehouse. At Kiwere the irrigation association has started to actively maintain infrastructure, including the canal and access road. At Silalatshani, the farmers have used the network developed with the Bulawayo Projects Centre to jointly negotiate with crop buyers. These changes are evidence that once irrigation communities have experience in problem solving techniques and confidence that they can effect change then they will direct iterative, self-reinforcing reforms. We expect such self-sustaining capacity to emerge in the other schemes involved in the project in the near future.

b) Innovation outscaling - that the innovations adopted through scheme specific AIPs become self-reinforcing and expand to other farming communities.

In terms of innovation outscaling, the project is starting to see application beyond the scope of the project. In Zimbabwe, the senior AGRITEX extension officers from both Insiza and Gweru districts have started to apply the innovations developed in the AIPs to the many other irrigation schemes in their district. There are twelve other irrigation schemes in Insiza District (excluding Silalatshani), with 726 irrigating households. In Gweru Rural District, there are six other schemes (excluding Mkoba), with 394 irrigating households. Six of these extension staff participated in the 'Training on agriculture innovation platform & farmers' soil & moisture monitoring tool kits' in February 2014. For instance in Insiza District, the improved market access developed in the project is being extended to nearby schemes. In Mozambique, INIR is using their experiences from the two irrigation schemes involved in the project to inform work at another eight pilot schemes throughout the country (in the provinces of Gaza, Manica, Sofala and Zambezia) benefiting more than one thousand farmers. This is part of the implementation of the new national regulations on irrigation scheme associations that requires, for example, development of association business plans and infrastructure maintenance. The challenge with AIPs is that each local process is unique and requires trained facilitators, making scale up labour intensive and expensive. Consequently, the second phase of this project will focus on outscaling of innovations developed in phase 1 to similar schemes, establishment of new AIPs only in schemes with substantially different issues, and establishment of AIPs at the district scale.

Full Stop and Chameleon sensors. The Full Stop and Chameleon sensors were installed with trained farmers at five schemes. Farmers who are monitoring solutes and moisture changed their irrigation scheduling to better match actual crop water demand, including for the stage of crop development and the type of crop being grown. They are using less water to irrigate. Farmers report applying water only a third as often as they did before the project. In this process, farmers have learnt to monitor soil fertility, not to wash nutrients away and of the benefits of applying compost and commercial fertilisers to increase crop yields. These tools have generated intense interest in the Tanzanian and Zimbabwean schemes, with farmers from outside the pilot plots and other schemes wanting to buy the equipment after seeing the tools in operation. The major challenge in scaling out is the prohibitive costs and time-consuming processes for importing the sensors from South Africa. We are collaborating with the ACIAR VIA Farm project to find: a) cheaper and more commercial means to meet demand from farmers for cheap sensors; and b) ways for governance institutions to use the now automated Chameleon data to strategically intervene to enhance irrigated agriculture.

In South Africa, the Full Stop and Chameleon sensors have been included a *Water Research Commission* (*WRC*) project, which started disseminating them to irrigation schemes in that country from 2016.

Project outputs: Mapping and clarifying the usage rights to irrigation plots has been a key output of the project (see community impacts below). The Tanzanian Irrigation Commission is assessing the method of mapping irrigation plots undertaken in the project for application nationally as required under their legislation. If this is implemented, this would lead to changes for improved management of the scheme and increased revenue collection. The same approach was undertaken In Mozambique, with mapping of irrigation schemes which was developed by other projects in irrigation subsector.

Organisation changes: In Mozambique, the INIR is using this project to develop a cadre of young professional staff who are skilled with both the AIP processes and the water and solute monitoring tools. The Director intends to use this enhanced staff capacity across Mozambique. In Tanzania and Zimbabwe agricultural extension staff are also using the project to build their institutional capacities to promote farmer learning, strengthen irrigation organisations and better engage with markets.

8.3 Community impacts – now and in 5 years

In all the irrigation schemes the outputs of the AIPs and simple tools have led to remarkable community impacts. As described in capacity impacts above, the AIPs and simple tools have instilled skills and experience, creating confidence among farmers that they can effect change leading to iterative, self-reinforcing reforms. Indicative of this impact is the renewed collection of water fees by irrigation associations in all three countries, leading to communal efforts to repair and improve infrastructure. Three further examples illustrate the community outputs and impacts.

In Mozambique and Zimbabwe, the project was a catalyst for discussions on what to do about unused irrigation plots. Outputs were the identification of plot holders and reallocation of unused plots to new farmers, providing opportunities for more young people and women to farm (detailed below for 25 Setembro irrigation scheme). A lasting impact is a process for reallocating unused plots and bringing new, younger farmers (and more women) into the irrigation communities. Full use of irrigation plots brings many community benefits, including generational renewal for irrigation associations and economies of scale in the market value chain and maintenance of irrigation infrastructure.

In Tanzania the Kiwere and Magozi irrigation associations are adopting better practices scheme management and their association constitutions as a result of visits to other irrigation schemes organised via their AIPs.

In Zimbabwe, full maize cropping data was collated and significant increases in crop yield and profitability were reported. One key impact is that farmers managed to send their children to schools, which was one of their major visions for their community when the project started in operation. One farmer at Silalatshani, a single mother said that project interventions have increased her the income so she could send her daughter to university, the first child from the scheme to receive a tertiary education (See Figure 5).

Figure 5: Sihle Sibanda and her daughter

There have been reports and testimonials (see Appendix 2 on Sihle Sibanda's case study) on the impact of changing farmers' mindset as they now take farming as a business rather than a platform to secure food for their livelihoods and families only. A sense of pride amongst farmers has developed, creating self-worth, with farmers now being able to invest in irrigation infrastructural maintenance and the project has brought various players with different roles and responsibilities together in trying to solve the complex issues hindering irrigation development. The AIP process has helped farmers to better elicit their problems and to find local solutions to these. There has been flexibility in the crop production calendars with the introduction of newer varieties and crops being introduced. Outputs reported by farmers include better linkages to input and output markets, as well as financial institutions, and better agronomic practices (e.g. use of organic manures, composting, and improved spacing).

8.3.1 Economic impacts

There have been considerable economic outputs and impacts, summarised here in terms of policy changes, land tenure and finance, more efficient resource use, and crop pricing and market access:

Policy changes. In Zimbabwe, the initial Silalatshani irrigation scheme AIP meeting identified the inability of farmers to pay a ZINWA scheme water bill, which by the time the project commenced was around US$280,000. In mid-2014, ZINWA delivered good news to the second AIP meeting, announcing a major policy change that they had written off the majority of the water bill debt. ZINWA indicated that they had recalculated the outstanding debt and offered the Silalatshani irrigators a reduced amount of US$80,000 (from the original debt of ~US$280,000) at 1% interest per annum to be paid off as soon as possible (as described above in section 1.2). There are many similar community irrigation schemes across Insiza and Gweru districts where the two study sites are located who are seeking to work with ZINWA to achieve similar results (for details see capacity impacts, AIP replication section).

In Mozambique, the new national legislation on regulation of irrigation associations informed by the project and which is being implemented in the two schemes, is having economic impacts. Unutilised plots are being reallocated enabling costs to be shared among more farmers and improving opportunities to lower costs through joint purchases. An output is the development of individual and scheme business plans which enable improved collection of user fees and underpin better infrastructure maintenance and operations.

Land tenure and finance. In both Zimbabwe and Mozambique, there were problems with unused plots in the schemes. At Silalatshani, following AIP meetings this issue is

now being addressed by district leaders (see section 1.3 above). Dealing with land tenure issues is complex in Zimbabwe, but this process is expected to have major, positive economic and social impacts. At 25 de Setembro, once the infrastructure repairs were completed, unutilised plots have started to be allocated to youth, and one plot is rented by a farmer from Zimbabwe.

Another issue emerging from the AIPs is that without clear land tenure farmers are not able to secure loans, for instance, to purchase agricultural inputs. In Mozambique, the new legislation requires all irrigation farmers to have identity cards, which enables farmers to access micro-finance. The project facilitated issuing of identity cards for the farmers at the two schemes in Mozambique. In Tanzania, the Irrigation Commission is exploring through Certificate of Customary Right of Occupancy (CCRO) ways to enable farmers' access to micro-finance to purchase bulk, quality agricultural inputs and avoid 'fake' products.

More efficient resource use. Improved knowledge of farm water use and nutrient management is increasing productivity at the irrigation schemes. In terms of outputs, farmers report in household surveys that since the project commenced they have reduced the number of irrigations by a half to a third and crop yields have increased 90 to 300%. While more fertilisers are being used, as there is less nutrient leaching leading to more effective use by crops. One impact has been that in water limited schemes more farmers are able to irrigate: in Kiwere tail-end plot holders have been able to crop, at the extensive Magozi scheme more plots are receiving water, and at Mkoba their limited dam water supply may now allow additional crops.

Pricing and markets. In each country, the research has improved profitability. Farmers have organised themselves to jointly purchase major farm inputs and services at lower cost. Micro-finance providers have been linked to irrigators. Analysis in all three countries has identified better crops and better production schedules to maximise market returns to farmers. Examples are detailed in the IJWRD papers, and include: better scheduling of vegetable crop production at 25 de Setembro; focussing on the two most profitable rice varieties at Magozi, milling the rice and using a warehouse to sell it at times when prices are higher; and trialling cash crops like garlic and ground nuts at Silalatshani.

8.3.2 Social impacts

The project has had and number of social outputs and impacts in terms of self-confidence, greater equity and reduced conflicts among the farmers as follows:

Age structure of the farming community. In Mozambique, the first AIP meeting in 25 de Setembro, the issue of the aging farmer population was identified. An output has been the admission of 17 young farmers who are being mentored by one of the more successful farmers and two elder farmers on the scheme. The new irrigation association regulations will accelerate admission of new, younger farmers with the requirement for associations to reallocate unused irrigation plots for ongoing impact.

Individual and community confidence. The individuals involved in AIPs, and using the Chameleon sensors and WFD, have renewed confidence and enthusiasm in their irrigation farming, This is reflected at a scheme scale (e.g. sub-scheme unit at Silalatshani) with renewed signage, committee work and community spirit. The soil and water monitoring equipment has triggered discussions among farmers on better farming practices, renewed activity of irrigation committees and resulting collective action. One example output is that the farmers in a sub-scheme unit at Silalatshani agreed to restructure their water schedule in the 2016-17 growing season to grow new cash crops. In Mozambique, community engagement has increased with the following examples of outputs: they have been actively engaged in business plan development and implementation, reallocation of unused plots and defence of their scheme from outsider land grabbers.

Credibility of process. An output with long lasting impacts is that the farmers have developed stronger networks as a result of project. Various organizations who were outside the project now associate themselves with the AIPs. For example, a number of organizations (see below) joined the AIP in Silalatshani due to its credibility. Several micro-finance institutions have held discussions with the farmers for credit and input access. In late 2015, the farmers were linked to United Refineries (Pvt Ltd) on a soybean contract farming venture. This was due to efforts from AGRITEX and an NGO, Technoserve. This shows that farmer now have an appreciation of a need to engage other players within the value chain which they did not do before the AIP project intervention. The participation of these organisations and contributions of their additional resources magnifies the project impact.

Teamwork, roles and responsibilities. The AIPs have fostered teamwork and the roles and responsibilities of various stakeholders have been clarified. For instance, ICRISAT is now working closely with a local NGO, Bulawayo Projects Centre (BPC) who held an event for AIP members called “A meet the farmer meet the buyer market forum” on 5 November 2015. Through the partnership, farmer ‘look and learn’ tours have been conducted at both schemes to visit entrepreneurial farms. An impact of this network development is that farmers at Silalatshani are now negotiating supply contracts directly with crop buyers in Bulawayo. Similar farm visits have occurred in Mozambique and Tanzania. Impacts in Tanzania are that both the Kiwere and Magozi irrigation associations are making changes to scheme management and their association constitutions as a result.

Reduced conflicts. An unexpected project impact is reduced conflict within the household and among farmers. At Kiwere, farmers report that using monitoring equipment has reduced competition for and squabbles over water access. Downstream farmers are scheduled by the irrigation association to irrigate from 7-11 am, and then upstream farmers irrigate after that. In the past, some upstream farmers 'illegally' diverted water into their plots during the time that downstream farmers should be irrigating, limiting the water that these downstream farmers receive, and forcing some downstream farmers to return in the night to irrigate. Now, with the monitoring equipment, the upstream farmers see that their soils are sufficiently irrigated and there is no need to divert water during the time that downstream farmers should be irrigating. Another example is from Zimbabwe, at the Landela Block in Silalatshani, where farmers are collectively working together to reduce conflict by fencing livestock out of the scheme; the farmers are making monthly contributions to buy the fence and working together to build it. Farmers report reduced household conflict as an impact of the project due to less time spent irrigating and greater household income that enables family goals (e.g. education of children) to be more readily achieved.

8.3.3 Environmental impacts

A key project impact is reduced irrigation frequency and reduced nitrate leaching into groundwater, benefitting the environment. For instance, the Zimbabwean team measured water use and calculated “water productivity”, figure 6. Analysis of the data indicates that water is being saved through skipped scheduled irrigation sessions, leading to a proposal to extend the current seven day cycle to save more water at the scheme.

Figure 6: Measuring water productivity at Mkoba irrigation scheme

Salinization is another important environmental issue, for example, on low-lying parts of Kiwere and at the Mkombilenga rice plots in Magozi. By reducing the irrigation frequency at these schemes we expect that salinity will abate. Further monitoring is required to ascertain the extent of salinity control.

Agrochemicals are poorly handled during the application process and agrochemical containers inappropriately disposed of in the schemes. In Tanzania, for example, the project has addressed these challenges through training and demonstration on best practices for nutrient, pesticide and herbicide management in the irrigated plots. This was organised by the project and delivered by agronomists from Syngenta and Bytrade. Further monitoring is required to ascertain the extent to which farm chemical management improves.

8.4 Communication and dissemination activities

In the initial period project, communication activities focused on introducing the project to stakeholders and establishing networks. Since 2014, many external communication activities were undertaken, including popular articles, academic publications and conference presentations. The publications are summarised in the attached ACIAR template. Key communication outputs include the following.

Article – In 2014, an article from Dr Mbakwe “What the Chameleon Said" won first prize in the open category of National Research Foundation (NRF) South African Agency for Science and Technology Advancement (SAASTA) Young Science Communicators competition. The results announcement can be found on: www.saastaresources.co.za/administrator/media/uploads/idv-2981042-404bd4497723e69122ec570b1c3b4dc2.pdf

Journal special issue – From 2015 to 2016, we synthesised the knowledge gained during the first two years of the project into nine research papers published as a special issue of the *International Journal of Water Resources Development* (IJWRD; available on request). These papers assess the situation in each of the three countries, as well as with respect to inequality within schemes, agricultural extension, smallholder irrigation, AIPs, farmer learning on soil and water management, and national irrigation policies. These papers synthesise the information from project surveys and other reports and were published as an open access special issue. The special issue was officially launched during two special sessions held at the World Water Congress in Cancun, Mexico in May 2017. See section 10.2 for the full list of papers.

Conference and meeting participation:

- Dr Mbakwe gave a talk on the development and use of the Chameleon soil moisture sensor at the South African National Committee on Irrigation and Drainage 2014 conference in Muldersdrift, South Africa.
- Dr van Rooyen shared the project with ICRISAT East and Southern African scientists at an Internal Review Meeting of research activity in November 2014.
- In July 2015, the "Sustainable Irrigation Development and Water Management for food security and Rural Livelihoods Improvements in a Changing Environment" Symposium was held in Harare, Zimbabwe. It was organized by ICRISAT in collaboration with the Ministry of Agriculture, Mechanization and Irrigation Development in Zimbabwe, and McGill University and financial support from ACIAR. Dr Andre van Rooyen presented lessons from the project AIP work; Dr Makarius Mdemu presented lessons from the research project in Tanzania; Mr Peter Ramshaw presented a project overview; Ms Sithembile Mwamakamba (FANRPAN) presented preliminary policy findings from the project. Those present included national and regional policy makers, development partners, researchers and farmers. Discussions at the symposium with Zimbabwean Government officials have led to a new policy project. The Symposium report is available on request.
- Mr Paiva Munguambe presented the project results regarding water and soil monitoring using of WFDs and Chameleon at the INIR Annual Council Meeting held in November 2015. Representatives attended the meeting from the Ministry of Agriculture, Provincial Directorate of Agriculture, technicians, INIR staff, local district authorities, extension officers from around the country and some NGOs.
- Prof Bjornlund gave a presentation on "Water Management: challenges and opportunities – a developing country perspective" at the XV World Water Council in Edinburgh, in May 2015,
- Dr Mbakwe also gave a presentation on "Improving irrigation water and solute management using simple tools and adaptive learning" at the Combined Crops, Soils, Horticulture and Weeds Congress in Bloemfontein, 18-21 January 2016. The co-authored conference paper by R.J. Stirzaker and J.G. Annandale won the award for the 'Best soil science paper on emerging agriculture'.
- Prof Bjornlund presented project related papers, by Ana Manero and by Prof Bjornlund at the International Commission on Irrigation and Drainage regional conference in Egypt, May 2016.April: One by Bjornlund: Increasing the productivity and profitability of small scale communal irrigation systems in south-eastern Africa and one by Manero, Isdory and Bjornlund: Why equity of irrigation water supply matters for economic equality.
- A paper by Prof Bjornlund has was presented at Sustainable small-scale irrigation and the African Business Community Conference of the Academy of African Business and Development, held in Arusha, also in May 2016.

- Dr Martin Moyo presented an Overview and lessons from the project: Agriculture and water in Mozambique, Tanzania and Zimbabwe on 8 March 2017 at the University of Pretoria at the launch of the ACIAR funded project titled “A Virtual Irrigation Academy to improve Water Productivity in Malawi, Tanzania and South Africa”
- Prof Bjornlund presented a paper Developing viable small-scale irrigation schemes in sub-Saharan Africa at the conference of the Academy of African Business and Development, Atlanta, Georgia 17-19 May.
- Ms Mwamakamba participated in a UNESCO-SADC special consultation session on water security under the theme “Water Security – Taking Communities beyond Short-term Relief” from 25-26 October 2016 in Gaborone, Botswana on the sidelines of the 17th WaterNet Symposium.
- FANRPAN co-convened and facilitated the participation of Ms Mwamakamba and Mr Augustine Mhike, the District Agriculture Officer from Silalatshani in the Water Session, which explored how multi-stakeholder processes can enhance the inclusion and recognition of rights of impoverished and marginalized user groups in policy design at the first African Soil Seminar from 28-30 November 2016 in Nairobi, Kenya.
- On April 10-12, 2017, Ms Mwamakamba participated in the 2017 Water for Food Global Conference and shared the project results
- On 30 March 2017, Ms Mwamakamba shared the project with FANRPAN Country Node Coordinators at an internal Node Coordinators meeting.
- Prof Bjornlund, A/Prof Pittock, Dr Mdemu, Dr Nuru Mziray, Dr Van Rooyen and Dr Moyo presented at the World Water Congress in, Cancun, Mexico, May 2017 to report the main findings from the project during a special session. This was chaired by the International Water Resources Organization, (IWRA). This platform was used to launch the special issue. Prof Bjornlund and the following papers were presented::
    - Andre van Rooyen, The transition of dysfunctional irrigation schemes towards Complex Adaptive Systems: The role of Agricultural Innovation Platforms
    - Nuru Mziray, The Use of Soil Monitoring Tools for Improving Crop Yields Through Better Management of Irrigation Water, Soil Nutrients, and Salt. Experience from Tanzania.
    - Makarius Mdemu, AIPs adoption, processes & application in two small holder irrigation schemes in Tanzania.
    - Martin Moyo, Breaking productivity barriers and utilizing opportunities: the use of Agriculture Innovation Platforms in small-scale irrigation schemes.
    - Jamie Pittock, Policy reforms to improve small-scale irrigation in Africa

9 Conclusions and recommendations

9.1 Conclusions

The smallholder irrigation schemes assessed in this research exemplified institutional failure. The combination of a complex range of problems meant that the irrigation systems were not profitable, were not maintained and eventually were under-utilised or abandoned. As a result the farmers reverted to averse, to low input, low output farming on lands with expensive agricultural infrastructure. Rebuilding the infrastructure does not address the underlying causes of poor performance; it only starts the cycle again.

The problems identified in the irrigation schemes were:

- lack of clarity over ownership of land and infrastructure;
- limited access to finance;
- government requirements to grow cheap, staple crops; expensive transport;
- fake and expensive farm inputs;
- limited farmer knowledge of agronomy (including water application and soil fertility);
- limited engagement between farmers and key markets; and
- low financial returns leading to limited reinvestment in irrigation associations and infrastructure.

All of these can be overcome with multiple interventions undertaken in this project, combining simple Tools and institutional reforms through Agricultural Innovation Platforms (TAIP). This project found that:

a) irrigation schemes are complex systems that require multiple different and complementary interventions at various scales to become more profitable and sustainable;

b) the key barriers are predominantly institutional;

c) donors and governments need to invest in people as much as hardware to overcome barriers;

d) governments need to clarify their objectives for small-holder irrigation schemes and develop appropriate business models to enable farmers; and

e) development of market linkages is required to sustain more profitable and sustainable irrigation.

This research has focussed on understanding the impacts of multiple interventions in six irrigation schemes. Building on this work, the next stage of this research in the project “Transforming Irrigation in Southern Africa” (LWR/2016/137) is investigating how such multiple interventions can be fostered at greater scales to transform more irrigation schemes more quickly.

9.2 Recommendations

The key recommendations emerging from this research on irrigation schemes in Mozambique, Tanzania and Zimbabwe are as follows.

a) Solving problems with multiple interventions in complex systems

The six irrigation communities studied illustrate that irrigation schemes are complex systems. While commonly perceived through the lens of their water infrastructure, the research reported here shows that a range of different social institutions need to operate well if irrigation schemes are to use natural resources sustainably, become profitable, and can thus afford to maintain irrigation infrastructure. Conversely, one ill-considered intervention may have a range of unintended and often negative consequences for irrigation scheme profitability and sustainability, as illustrated by a frequent government requirement to grow unprofitable staple food crops, leaving no incentives for increased investments.

The project demonstrated that multiple, concurrent interventions identified, tested and implemented by the stakeholders themselves are required to transform these small holder irrigation schemes into new, more profitable and sustainable states. In most schemes, an initial successful intervention engendered the trust and commitments needed for farming communities to begin changes that are more challenging. The initial gains for farmers from the soil and water monitoring tools, which increased their crop yields and reduced labour, generated a willingness to discuss other barriers and opportunities through the AIPs. Then within the AIP processes at Silalatshani, for example, the AIP's role in facilitating an agreement for reducing the debt on water to the government was a catalyst for the farmers to embrace trials of new crops and water scheduling systems. Similarly, with the AIP at 25 Setembro, the government's willingness to help repair infrastructure generated the goodwill to tackle harder problems, like reallocating unused farm plots to new, young farmers.

These complex irrigation systems require different and complementary measures (at various scales) to become more profitable and sustainable. This shift will include greater equity and ownership, increased cooperation between all stakeholders, information sharing and learning, developing local adaptive strategies to evolve in response to their own pressures and opportunities.

b) Invest in people as much as hardware to overcome multiple barriers

Hard barriers are the physical limits to more successful irrigation associated with availability of resources like land and water, and of infrastructure. At Mkoba, for example, limited storage capacity has meant that irrigation water supplies have been exhausted in the 2015-16 drought. Soft barriers are where key services are not available, including where institutions prevent successful farming. In Tanzania, for example, farmers were unable to access finance to buy farm inputs until they acquired a certificate of customary occupancy of their land, which was a difficult bureaucratic process. It may be possible to issue similar, formal documentation of land use entitlement in other countries.

The research in Mozambique, Tanzania and Zimbabwe showed that there are multiple soft and hard barriers that need to be addressed in an integrated way if irrigation schemes are to be transformed to more profitable and sustainable states. In Mozambique, the poor state of the pumps and canals meant that the local people were not ready at first to address the challenges of lowering input costs and finding profitable markets for their produce. At 25 Setembro, once there was progress towards repair of the physical infrastructure the farmers then embraced people-centred reforms, such as reallocating

unused plots to younger farmers, accessing certified seeds and scheduling production to better match market demand.

In general, at each of the six schemes the soft barriers were most limiting for the farmers. In particular, primary concerns were reducing costs and increasing the investments in crop inputs while growing crops that would meet market demands and maximize returns. Greater donor and government investments in people and institutions is needed to help smallholder irrigation schemes to become more profitable and sustainable. In this project, AIPs were able to bring diverse stakeholders together to resolve issues and foster improved relations, building the local capacity to innovate and work towards collective goals are very powerful incentives for change.

c) Governments need to clarify their objectives and empower farmers

The poor state of the smallholder irrigation schemes before this project started should be a salutary warning to the donors and African governments who seek expansion without addressing the underlying reasons for this poor performance.

Governments should not undermine the objectives of reducing poverty, increasing food security and economic growth by imposing rules that constrain farmers' abilities to access more land within schemes and produce crops that are more profitable. We argue that the focus should be on poverty reduction by enabling smallholder farmers to produce profitable crops for local markets, to expand their enterprise where they can within a scheme and increase household income.

While staple food crops may not be grown in irrigated plots, greater household income should enable such food stuffs to be purchased, boosting local agricultural markets, or grown on the irrigation farmers' dryland plots (such as at Silalatshani and Mkoba). In other words, governments need to reconsider the concept of food security and move away from a focus on producing staple food on irrigation schemes to allow farmers to grow profitable crops to be food secure. There is a dire need to define the role of irrigation systems in developing countries and develop business models and management strategies suitable for those objectives.

Power structures are critical to unleashing the potential of farmers to create a more viable irrigation-based economy. At all six schemes the irrigation associations were too weak to perform basic functions like maintaining infrastructure, organising collective purchases of services and scheduling production to maximise returns, therefore farmers were not paying user fees. We raise the question of whether successful irrigator associations compete for status and authority with local governments, traditional authorities and local offices of national government agencies.

For the schemes to succeed the irrigation associations, need to be developed towards a substantial autonomous and adaptive capacity. For this to occur national governments, need to clarify responsibilities and enable irrigators more while directing less. The recent reforms of Mozambique irrigation regulations are a strong step in this direction by providing the mandate and responsibility for irrigation associations to become self-funding, develop and implement business plans so as to become more autonomous (Mwamakamba et al., 2017).

The barriers and opportunities described above highlight the vital roles that information and effective institutions play in the development of responsive, profitable and more sustainable farming systems that are more resilient. Donor and government irrigation scheme developers need to invest in empowering farmers to make informed choices in the context of the larger system.

d) Markets as incentives for change

Research at the six irrigation schemes illustrates the need to harness the power of the markets to transform irrigation systems. In none of the schemes were farmers able to afford to pay water use fees sufficient to maintain irrigation infrastructure. The irrigation schemes will only be capable of self-renewal if farmers are able to produce crops that are more profitable. As described above, changes in government policies are important for enabling the development of more profitable farming. Yet our research shows that there are many steps that farmers and businesses can take to increase returns for stakeholders in the local agricultural economy.

The AIPs provided previously unrealized opportunities for farmers to define barriers and opportunities, and then engage the relevant stakeholders in the agricultural value chain to identify mutually beneficial changes. This has meant that farmers have been able to purchase higher quality farm inputs and transport services in bulk, reducing their production costs. It has also enabled farmers to understand from purchasers the type and quality of agricultural produce and timing of supply required to earn higher prices. As a result, many irrigators at these schemes are moving from subsistence to more market oriented farming with the assurance of more reliable and profitable markets.

It is the increase in returns and resulting change of mindset among farmers, that is increasing pressure from them on governance institutions to better support irrigation farming. In our view, it is this positive reinforcement from the agricultural market that will enable more sustainable and profitable irrigation. Markets provide both the incentive and the means to invest.

In the follow up project “Transforming Irrigation in Southern Africa” (LWR/2016/137), we shall again collaborate with ACIAR and develop new partnerships to identify ways of implementing these recommendations more quickly and at greater scales.

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10.2 List of key publications produced by project

A detailed list is contained in Appendix 3.

Bjornlund, H., & Pittock, J. (2017). Exploring the productivity and profitability of small-scale communal irrigation systems in Sub-Saharan Africa. *International Journal of Water Resources Development, 33*(5), 685-689. doi:10.1080/07900627.2017.1326881

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Wheeler, S. A., Zuo, A., Bjornlund, H., Mdemu, M. V., van Rooyen, A., & Munguambe, P. (2017). An overview of extension use in irrigated agriculture and case studies in south-eastern Africa. *International Journal of Water Resources Development, 33*(5), 755-769. doi:10.1080/07900627.2016.1225570

11 Appendixes

11.1 Appendix 1: Summary analysis of the on-line monitoring data

On farm crop monitoring totalled 208 crops. Of these 133 were considered to be complete data sets, meaning that there was at least a Chameleon colour pattern and yield (Table 4). Partial crops are either those that have no harvest date or crop yield recorded. Further work is underway to see if this missing data can still be sourced. The data split into countries in shown in Table 5.

Table 4: Number of crops monitored by year

Year	Complete	Partial	Total
2014	14	20	**34**
2015	47	13	**60**
2016	72	42	**114**
Total	**133**	**75**	**208**

Table 5: Number of crops monitored by country and year

Year	Zimbabwe		Tanzania		Mozambique		Total
	Complete	Partial	Complete	Partial	Complete	Partial	
2014	0	0	14	1	0	19	**34**
2015	25	10	22	3	0	0	**60**
2016	26	17	0	22	46	3	**114**
Total	**51**	**27**	**36**	**26**	**46**	**22**	**208**

The progress at each scheme in using water and increasing yields can be tracked on the VIA platform (www.via.farm).

When using the latest version of the Chameleon technology, the colour patterns are created automatically on the VIA when a project worker or farmer takes a reading in the field. Yields and other agronomic data must be added manually. The VIA then aggregates the data and allows it to be interrogated and summarised by crop, year, scheme, project or country.

For each scheme on the following pages, the table shows the crop type, year of planting, number of each crop type monitored, number of crops with yield recorded, minimum, maximum and average yields of each crop in each year and the average number of data uploads per week. If the 'detail' icon is selected, the next screen will show data for all crops linked to that line i.e. from crop 'x' in year 'y'. If the 'detail' button is selected on the next screen it takes the user to the actual colour pattern for that particular crop and any agronomic data and farmer comments recorded against that crop.

Although the data set is quite large (133 completed crops), there are no clear trends in yield with time. This is strange as the formal quantitative data does not match with the qualitative data from focus groups and other sources, which claim large increases in yield. Some reasons for this may include:

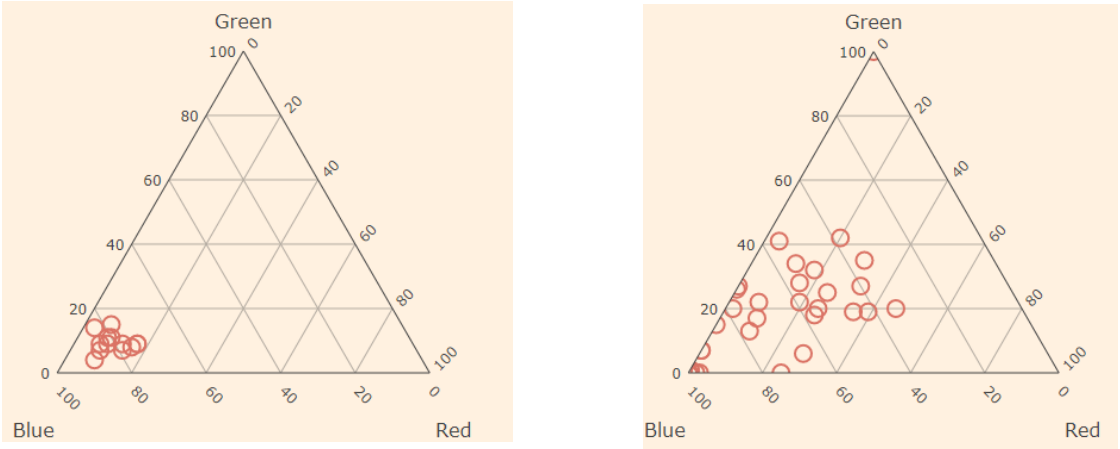
- The data from the 75 incomplete crops may hold the missing data. For example, there is maize yield data at Silalatshani for 2015, but not 2014 and 2016, whereas the bean yield data exists for 2016, but not 2015 and 2017.
- There may be real yield data compiled from sources other than the monitoring program, such as experiments to determine water use efficiency.
- The yield improvement data may come from a few early adopters and this is not reflected in the broad averages.

The current mismatch in qualitative and quantitative information presents a significant challenge to the project as it seeks to upscale and provide reliable evidence to new investors. This also plays into the debate about how much information should a project like this collect, and what degree of quality control is needed for different investors. Analysis of the BACI household survey data, currently underway, will provide a separate source of data to inform this discussion.

On the other hand the soil water data provides very strong evidence of over-watering. For example we can summarise a whole season as percentage of time the root zone was blue, green or red. Thus a farmer's season can be plotted as a single point in a triangle (say 70% green, 20 % Green, 10% Red), in much the same way as a soil comprised of sand, silt and clay is located in a 'texture triangle'. When each farmer growing the same crop on a scheme is plotted, we can observe dominant behaviours. Yields can be linked to each plot in the triangle, and then shifts in the location of plots in the triangle can be analysed over time. This provides a quantitative measure of the final result of what farmers have learned i.e. change in water management and resultant change in yield. This is the kind of data that could be used as evidence of more efficient water use in irrigated agriculture.

An example is shown for Mkoba and Boane schemes, figure 7. Mkoba is kept very wet with the average root zone spending >80% of time in the blue zone, while Boane shows a much greater spread of blue, green and red. The average maize yield at Mkoba was 2.1 t/ha (14 crops) whilst the average yield in Boane average yield 4.6 t/ha (37 crops). At this stage this is circumstantial evidence, as we need to see the shifts in water management, colour patterns and yields at each scheme over time. Yet the evidence does appear convincing to farmers and they claim to be making appropriate changes to their irrigation practices.

Figure 7. A comparison of the blue, green, red colours for maize at Mkoba (14 crops, left) and Boane (37 crops, right).



Zimbabwe – At the Silalatshani scheme, 50 crops were monitored of which 24 are complete. The main crops were maize and sugar beans. We do not yet have data showing the same crop over different years at Silalatshani so cannot make any assessment of yield changes in yield over time. The scheme was very wet, with 90% of the depth average time in the blue zone.

Farm: **Silalatshani irrigation scheme**

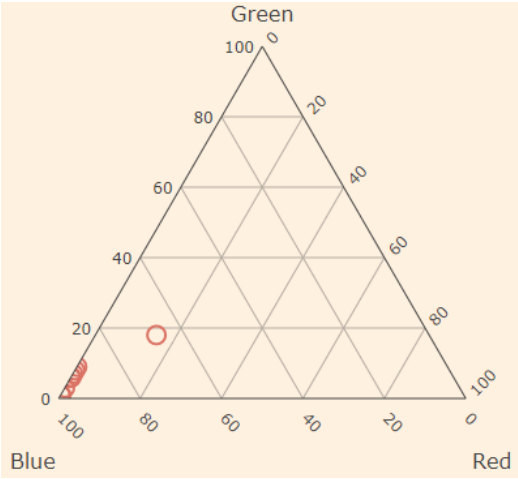
Past crops

Crop Type	Year	Number of crops	Number with yield data	Min Yield	Max Yield	Avg Yield	Avg Uploads per week	Detail
Maize	2015	11	11	0.1	5.6	3.4	1.0	
Sugar beans	2016	13	13	1.0	3.5	2.0	1.1	
Total:		**24**	**24**					

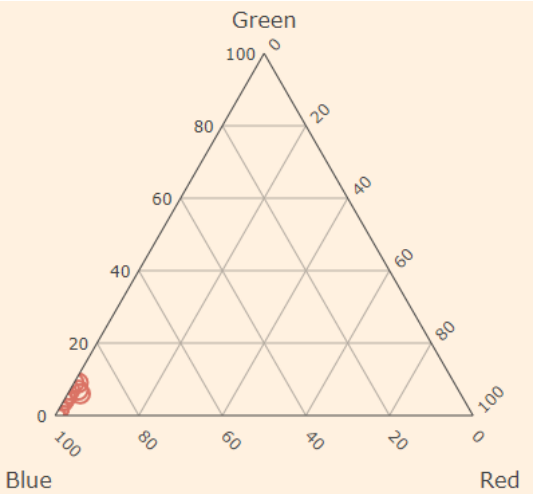
Current crops

Crop Type	Year	Number of crops
Maize	2015	7
Maize	2016	15
Sorghum	2016	2
Sugar beans	2015	2
Total:		**26**

Maize 2015 (11 crops)



Sugar beans 2016 (13 Crops**)**



At the Mkoba scheme, 27 crops were monitored of which all 27 are complete. The main crops were maize and sugar beans. We do not yet have data showing the same crop over different years at Mkoba so cannot make any assessment of yield changes in yield over time. The maize crops were kept very wet, but the sugar beans showed very variable water management.

Farm: **Mkoba Irrigation Scheme**

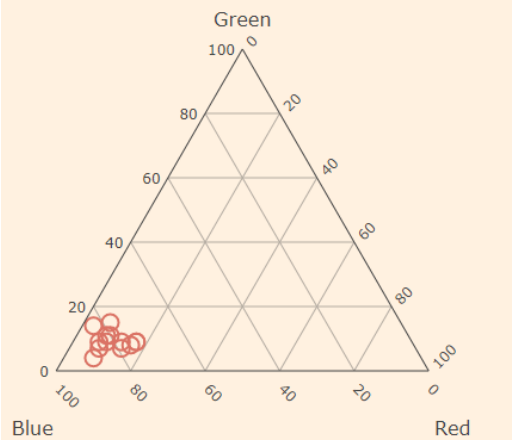
Past crops

Crop Type	Year	Number of crops	Number with yield data	Min Yield	Max Yield	Avg Yield	Avg Uploads per week	Detail
Maize	2015	14	14	0.5	6.5	2.1	0.9	
Sugar beans	2016	13	13	0.2	1.8	0.8	0.6	
Total:		**27**	**27**					

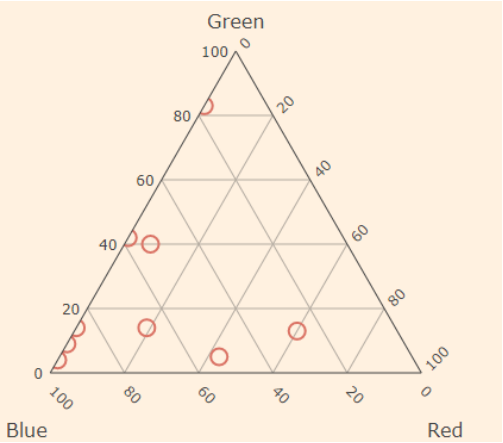
Current crops

Crop Type	Year	Number of crops
Maize	2015	1
Total:		**1**

Maize 2015 (14 crops)



Sugar beans 2016 (13 Crops)



Tanzania – At the Kiwere scheme, 62 crops were monitored of which 36 have complete data. The main crops were green maize, onions and tomatoes. There is some confusion over which of the maize crops are green-maize and which are seed-maize. Some yield comparisons can be made for tomatoes with the average yield in 2014 of 15.8 t/ha (13 crops) and the average in 2015 of 14.9 t/ha (3 crops). The 2014 tomato crop was mostly blue, although with a dry period (red) mid-season, whereas the green maize crop was blue with some green periods.

Farm: **Kiwere Irrigation Scheme (ANU)**

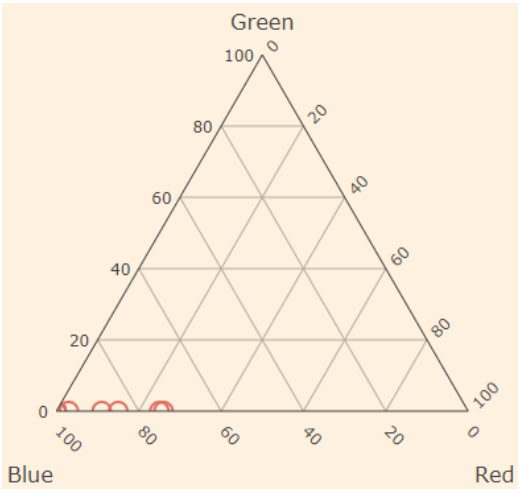
Past crops

Crop Type	Year	Number of crops	Number with yield data	Min Yield	Max Yield	Avg Yield	Avg Uploads per week	Detail
Eggplant	2014	1	0	–	–	–	0.6	
Maize	2014	1	1	3.0	3.0	3.0	0.6	
Tomato	2014	13	13	8.6	23.6	15.8	0.5	
Maize	2015	17	17	8.6	21.0	14.1	1.8	
Maize (Green)	2015	1	1	21.0	21.0	21.0	1.8	
Onion	2015	2	1	6.3	6.3	6.3	1.6	
Tomato	2015	3	3	9.2	22.5	14.9	0.9	
Green Pepper	2016	2	0	–	–	–	1.8	
Maize	2016	6	0	–	–	–	1.9	
Onion	2016	3	0	–	–	–	1.9	
Tomato	2016	1	0	–	–	–	2.0	
Total:		**50**	**36**					

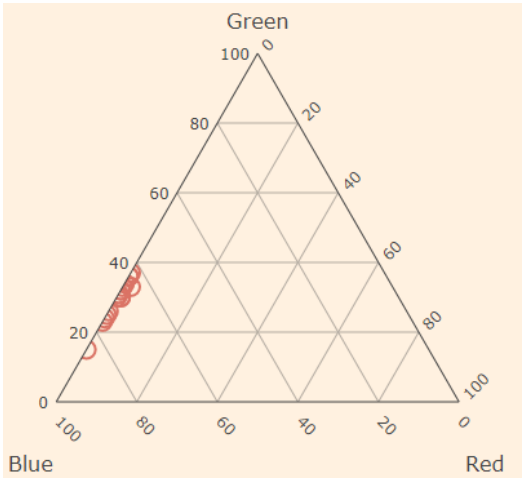
Current crops

Crop Type	Year	Number of crops
Onion	2015	1
Tomato	2015	1
Eggplant	2016	1
Garlic	2016	1
Maize	2016	1
Onion	2016	3
Tomato	2016	4
Total:		**12**

Tomatoes 2014 (13 crops)



Maize 2015 (17 Crops)



Mozambique - At the Boane scheme, 68 crops were monitored of which 46 have complete data. The main crops were maize and cabbage. Almost all the data comes from 2016, so no yield comparisons over time can be made. Boane plots showed the highest percentage of green and red and also recorded the highest maize yield – an average of 4.6 t/ha (37 crops measured)

Farm: **Boane Irrigation scheme**

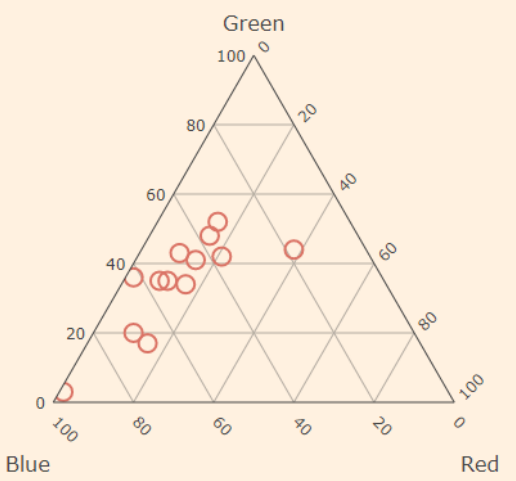
Past crops

Crop Type	Year	Number of crops	Number with yield data	Min Yield	Max Yield	Avg Yield	Avg Uploads per week	Detail
—	2014	1	0	—	—	—	0.5	
Cabbage	2014	4	0	—	—	—	0.6	
Chili	2014	1	0	—	—	—	0.6	
Maize	2014	13	0	—	—	—	0.6	
Beans	2016	1	1	3.1	3.1	3.1	1.0	
Cabbage	2016	4	3	4.7	14.0	8.0	1.6	
Chili	2016	2	2	0.8	0.9	0.8	1.1	
Cucumber	2016	1	0	—	—	—	3.3	
Eggplant	2016	2	2	2.7	4.9	3.8	1.1	
Maize	2016	38	37	2.3	8.6	4.6	1.1	
Tomato	2016	1	1	14.0	14.0	14.0	1.0	
Total:		**68**	**46**					

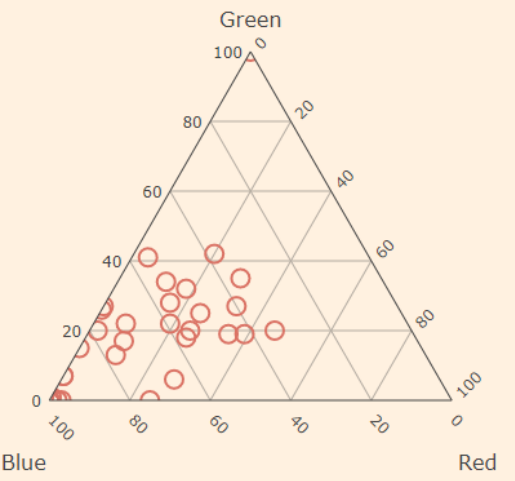
Current crops

Crop Type	Year	Number of crops
Total:		**0**

Maize 2014 (13 crops)



Maize 2016 (38 Crops)



11.2 Appendix 2: Sihle Sibanda Case Study

Four years ago Sihle Sibanda was planning to move to the city to try to find work. She was trying to support her daughter through her schooling, and was finding irrigation farming difficult. Today, not only is she the Chairlady of the Landela Block Irrigation Management Committee, but she has paid for her daughter's university education and is an outspoken advocate for farming as an income source and business model. And it is that very thinking – that farming is a business – which she hopes to pass on to other irrigation farmers in the future.

Through farming within the "Increasing irrigation water productivity in Zimbabwe" project, and being exposed to new farming technologies and the Innovation Platform model at the core of the project, she is one of many success stories – proof that by tackling the complex irrigation system at multiple levels with different interventions, higher yields and higher profits are possible.

Factors including poor management, limited links to markets, limited water availability and government policy have all impacted farmers ability to get maximum benefit from their fields, and create a sustainable livelihood. Sihle recounted how in the past farmers in her irrigation scheme just used to water their fields when there was water in the canals. "We couldn't just let the water go past". But with the introduction of the Chameleon and Fullstop technology – tools which measure and monitor water and nutrient levels and indicate when the water and fertiliser is actually needed, rather than relying on guesswork or older farming practices - she listed the benefits. "There is now less leaching because there is not too much water draining the soils… I am saving money because I no longer need to buy as much fertiliser or use it unnecessarily… and I am saving time" which she can now spend doing other things.

This time saving is a key component found across the irrigation scheme. Sihle says she spends her extra time being part of clubs – micro-finance clubs, women's clubs – as well as doing other farming work that in the past she might have had to pay extra labour to do. She can also invest time back into the irrigation scheme itself, helping to clean the canal banks and working through the Irrigation Management Committee to educate other farmers.

She believes education is key, and has been one of the best outcomes from the last four years of this project. And something that should be expanded in the future too. She spends much of her time working with the older farmers on the scheme, helping them adapt to the new technologies. She is quick to say there is no conflict and no discrimination on the scheme, but "patience is needed as a young farmer" when helping the older farmers to recognise the benefits of the new technology and information.

Money saving too is of course a major benefit, and one Sihle has put to good use, on education and purchasing livestock. She considers livestock her retirement fund, when she can no longer farm the fields, livestock will provide income for her. Their manure feeds her fields and they can be fed using residue from the fields. "If the fields fail, the livestock won't. They don't require any labour, and produce continuously."

Sihle is also very vocal in her support of the Innovation Platform's stakeholder engagement model, especially bringing farmers and the markets they are selling to together. It is this understanding of how the markets work, and what they need and how farmers like herself and the others on the Landela Block can provide this, which is the real breakthrough of the project.

She admits in the past it was the limited access to the markets, their distance away and related transport costs, and the farmers' inability to provide what it was the market needed and wanted that was holding the local farmers back. Now, with the inroads, introductions and awareness, it is up to farmers to adapt and work within the markets and grow and sell what will benefit them the most.

"Many farmers think that to have a business is to have a shop, but they need to see their plots are businesses too." She believes workshops should start with changing farmers' minds, and teaching them to be more "business minded."

Also learning about cropping practices, micro-dosing of fertiliser and most importantly how to budget production costs and inputs and outputs have all added to a more holistic understanding of farming, and the ability to make informed, educated decisions. She is keen to say farmers are too afraid of losses and don't take enough risks, will not borrow money to expand their plots and inputs for better yields. Her vision is to try to encourage her neighbours to grow and invest in farming and get away from the "loss mentality".

Given so many young people are leaving the land or choosing not to farm their family plots, she sees her role as showing younger farmers that farming is a money making option, and they do not need to leave the land for the cities to survive. She believes that the farmers on the ground need to show young people all the things they have bought and done with their profits – livestock, education, housing – to prove that farming, when done properly, is a viable option.

11.3 Appendix 3: Final annual report publications

For a detailed list of all communications and publications see separate ACIAR template excel file ‘FSC-2013-006 -Final-annual report publications appendix.xlsx’.