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Moving from case studies to whole of industry: Implementing methods for wider industry adoption

Final Report of SRDC Research Project CSE009

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The principal investigators request that the appendices of this report are not distributed without their consent.

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EXECUTIVE SUMMARY

This project was funded by SRDC, in partnership with CSIRO Sustainable Ecosystems and James Cook University. The project commenced in July 2003 and this final report, completed in March 2008, summarises the key outputs, outcomes and lessons that have emerged from the project.

The issue

Sugar production systems are characterised by complex interactions between economic, ecological and social components, including climatic and biophysical variability and uncertainty and multiple decision-makers. The development of decision support systems (DSSs) has been one way in which scientists have attempted to help agricultural industries deal with this complexity. Participatory action research (PAR) approaches have become increasingly popular in the development of DSSs, in an attempt to increase their usually low adoption rates. As the knowledge intensiveness of technological innovations increases, so does the need for PAR, to ensure the relevance and effectiveness of the new technology. With significant transitions towards more participatory research and the development of DSSs it is imperative that the R&D community gains a deeper and richer understanding about the participatory development of complex technologies so that associated environmental, economic and social outcomes can be realised by industry.

The R&D methodology

The R&D methodology for this project was based on participatory action research. The R&D methodology was also inspired by concepts within science and technology studies. Science and technology studies describe how science and technology are produced through social relationships and practices. The resulting theoretical framework that was developed through this project provides a new perspective on participatory DSS development, which is richer than the traditional diffusion of innovations perspective.

The R&D methodology ensured that the development of the theoretical framework was underpinned by ongoing stakeholder participation. The three project team members, experienced variously in climate forecasting applications, irrigation and nitrogen management research, established case study groups in various sugarcane growing communities across Australia. Climate forecasting case study groups were initialised in Tully, Plane Creek and Northern NSW. Irrigation case study groups were established in Plane Creek and Bundaberg, and the Tully climate forecasting group also served as the nitrogen management case study group. The theoretical framework emerged following extensive interactions between social science researchers, technology researchers and industry stakeholders. Extensive interviews were conducted to assess the validity of the theoretical framework and evaluate the impact of technologies developed in the project. Further, expert opinions of researchers within and external to the sugar industry were canvassed through a workshop designed to collect feedback on the validity of the theoretical framework. The interviews and external consultation process revealed that the theoretical framework offers a new and valuable way of thinking about participatory development of complex technologies.

Outputs and outcomes

The project produced several outputs and outcomes. Pivotal to the project was the development of the theoretical framework that connected theories from science and technology studies with the participatory development of decision support systems. This

framework provides a mechanism for researchers to understand how their technology is more likely to be adopted and applied in practice. Ultimately, this knowledge can provide researchers with more understanding and confidence about how to engage with a case study group, creating a more efficient and effective process. This in turn can accelerate the enhancement of industry activities by better identifying and overcoming obstacles that can delay progress and identifying improved technology development processes and adoption pathways.

Another important area of outputs and outcomes relates to the active participation of sugar industry members in the development of technologies and management recommendations for improved application of seasonal climate forecasting, improved irrigation scheduling and reduced environmental impacts of nitrogen fertiliser management in the wet tropics. Outputs to better manage limited water supplies (WaterSense) and increase industry preparedness to swings in climate variability (RainForecaster) were developed as part of this project. Extensive consultation and R&D was required so these outputs satisfied end-user needs and expectations. Moreover, the project team is confident that substantial benefits from these technology tools will continue to be delivered to industry once this project has been completed. Ways to reduce environmental impacts of nitrogen fertiliser management were identified and adopted by some case study group members. The general understanding of nitrogen cycling and the fate of fertiliser was also increased amongst the case study group.

The mutual learning intended by Participatory Action Research was a significant outcome of this project.

Impact

Many of the challenges that the sugarcane industry faces are complex systems issues and R&D addressing these issues requires the active participation of industry stakeholders. A deeper understanding of processes that contribute to effective engagement between researchers and end-users is therefore essential to deal with the ongoing and evolving complexities of sugarcane systems. Without this knowledge, millions of dollars of R&D investment will be wasted and immeasurable environmental, social and economic benefits will be lost. The framework developed in this project has the potential to improve the way in which participatory research and technology development are conducted. However, in order to realise these impacts, the framework needs to be further developed to more clearly guide interactions between scientists, extension officers and farmers. Building capacity within the industry to implement learnings from this framework could help maximise the impact of complex technologies in the Australian sugarcane industry. This will assist the industry to profit rather than suffer from the complex challenges that it faces.

BACKGROUND

This section of the report provides background on agricultural decision support systems, participatory DSS development approaches and sociological concepts for understanding participatory DSS development and application.

Agricultural decision support systems

Like most agricultural systems, sugar production systems are characterised by complex interactions between economic, ecological and social components, including climatic and biophysical variability and uncertainty and multiple decision-makers (Jakku *et. al.*, 2007). Many of the management decisions made by growers need to be adaptive and dynamic, and must take into account uncertainty and unpredictability (Ridley, 2004). Furthermore, trends such as the intensification of agricultural production, globalisation and growing concerns about the environmental impacts of agriculture have meant that decisions within the sugarcane industry and agricultural industries in general are becoming even more complex (Lynch, Gregor & Midmore, 2000; Walker, 2002). This increase in complexity is linked to a search for ways in which scientific knowledge can be incorporated into forms that farmers can use to assist their farm management decisions. The development of agricultural decision support systems (DSSs) is one way in which scientists have attempted to make agricultural systems science more accessible and useful for guiding the management of production systems (McCown, 2002a).

The rationale for the application of DSSs to farm management is generally based on the argument that DSSs provide a means for agricultural scientists to capture, assimilate and deliver to farmers and their advisers useful information and procedures for decision-making that should help farmers to better manage their farms (Hayman, 2004; Stone & Hochman, 2004). Knowledge intensiveness is one of the defining attributes of agriculture DSSs. Unlike knowledge embedded innovations, such as new seed varieties where all the new knowledge associated with the innovation is embedded in the innovation itself, complex technologies such as DSSs require users to acquire new knowledge and skills to operate the technology effectively and interpret its outputs (Audirac & Beaulieu, 1986; Douthwaite et al., 2001).

Despite the initial optimism and the significant resources that have been devoted to agricultural DSSs, developers of these DSSs found that influencing farm management practice proved to be far more difficult than they first envisioned (McCown 2002b; Hayman, 2004). There is widespread recognition that DSSs have had at best a very limited impact on farm management and this is supported by a large body of literature that addresses this problem of implementation of agricultural DSSs (e.g. Cox, 1996; Lynch, Gregor & Midmore, 2000; McCown, 2002a, 2002b; McCown et al., 2002; Stephens & Middleton, 2002; Hayman, 2004). McCown (2002b) draws on the history of the problem of implementation experienced by Operations Research and Management Science to argue that the low uptake of DSSs by farmers is part of a more general trend of limited adoption of information systems technologies. McCown (2002b) also points out that the form of particular DSSs has an important influence on their adoption rates. DSSs that act as proxies for decision-making are only appropriate for situations characterised by well-defined, narrow-domain problems that can be delegated by farmers and advisers. DSSs that act as tools to enhance the decision-makers' process have a greater chance of broader adoption, provided that they are perceived as useful and offer a significant net benefit to the decision-maker.

The limited uptake of agricultural DSSs has prompted critical reflection on the process of developing and implementing DSSs, in a search to find new ways in which to improve their adoption rates. For instance, Cox (1996: 376) advocates the need to 'renegotiate the criteria for success in DSS research', to focus on 'the critical insights gained through improved communication of the different perspectives of researcher and farmer.' Similarly, Walker (2002) suggests that DSSs can have a greater impact if used as learning and co-learning tools, rather than as practical decision aids. Thus, Walker (2002: 115) argues that:

> …many DSS initiatives that have not resulted in significant operational use have nevertheless been judged to have been successful on the basis of the learning achieved by the developers and users, particularly where development has been highly participatory.

Bellamy and Lowes' (2000) study of the development of a DSS for sustainable grazing management extends this point by recognising the potential of DSSs to generate a broad range of impacts, including intangible outcomes such as co-learning and improved researcher and stakeholder interaction.

This reappraisal of the role of agricultural DSSs has led to a search for a new paradigm to underpin the development of DSSs. McCown (2002b, p. 181) argues that this search for a new paradigm for the way in which DSSs are built and used is characterised by a focus on 'how to achieve "mutual understanding" between interventionists and practitioners…', where intervention 'is less about recommendation that by-passes a farmer's decision process and more about facilitation of decision process adaptation.' As a result, developers of agricultural DSSs have turned to more participatory approaches to the development of these technologies, in an attempt to improve the adoption and impact of DSSs.

Participatory DSS development

The limited uptake of agricultural DSSs has been partly attributed to the dominance of technology-centred rather than user-centred approaches to the design and development of DSSs (Lynch, Gregor & Midmore, 2000; Walker, 2002). Thus, participatory approaches have received an increasing level of attention as a means of enhancing the relevance and impact of agricultural DSSs. Participatory approaches, concepts and methods have been developed in a range of disciplines, including rural and community development, the social sciences, public and community health, education, agricultural systems and natural resource management (Cornwall & Jewkes, 1995; Parkes & Panelli, 2001). It is therefore difficult to neatly categorise the wide range of models of participatory research and development. However, recognition of the importance of the relationship between researchers and stakeholders is central to participatory approaches (Ashby, 2003).

The growing appreciation of the value of participatory approaches is part of a paradigm shift in the way in which the research and development process is envisaged. For instance, through the involvement of relevant stakeholders in the development of agricultural DSSs, the use of participatory approaches can help developers of these DSSs to better understand farmers' needs and motivations. The use of participatory approaches to DSS development is underpinned by adult learning principles and involves farmers and researchers cooperating as active co-experimenters engaged in joint learning (Ridley, 2004). Lynch, Gregor and Midmore (2000) argue that the use of participatory approaches in the development of agricultural DSSs can result in products that are perceived as more useful and easy-to-use and are therefore more readily adopted. This is partly because the use of participatory approaches ensures that the development of the DSS takes into account the needs of potential users and is therefore more likely to have the attributes identified by diffusion theory as important for successful adoption; namely high relative advantage, compatibility and trialability, low complexity and an appropriate communication process. Similarly, Walker (2002) maintains that a participatory action research framework can ensure that the development of DSSs integrates researchers', developers' and users' perspectives in order to clarify objectives and foster learning and co-learning.

Sociological concepts for understanding participatory DSS development

The use of participatory approaches to the development and application of agricultural DSSs highlights the need for new ways of thinking about the process of designing and implementing DSSs. Part of this approach to DSSs involves a greater emphasis on the social dimensions of the process of developing DSSs. Science and technology studies are one area of literature that has so far remained relatively untapped in this search for new ways in which to understand the social processes involved in participatory DSS development.

The sociology of scientific knowledge highlights the way in which 'scientific knowledge is not the passive product of nature but an actively negotiated, social product of human inquiry' (Cozzens & Woodhouse, 1995: 534). Similarly, the sociology of technology focuses on investigating the way in which technology is 'a social product, patterned by the conditions of its creation and use' (Williams & Edge, 1996: 866). There are a number of concepts within the science and technology studies that can help examine the influence of the social context on participatory development of agricultural DSSs and the social processes involved in the operation of DSSs. The major relevant concepts are: interpretative flexibility, technological frames and boundary objects. When combined, these concepts provide valuable insights into the ways in which different social groups make sense of, and interact in the development of complex technologies such as agricultural DSSs. The theoretical framework developed in this project combines these concepts in order to identify new insights into the participatory development and application of decision support systems in the Australian sugarcane industry.

OBJECTIVES

The aim of this project was to improve understanding of the way in which complex and knowledge-intensive technologies become developed, adopted and applied in practice.

The three objectives that guided this project were to:

1. Extend knowledge of the participatory technology development process to improve understanding of the adoption of complex technologies.
2. Build understanding and application of complex and emerging technologies (climate forecasting and crop model based decision support tools) through case studies across multiple regions.
3. Identify pathways that can potentially lead to the wider adoption of complex technologies.

This section details how the project has met each of these outcomes.

1. Extend knowledge of the participatory technology development process

The theoretical framework developed in this project provides a richer understanding of the participatory development and adoption of complex technologies. This framework evolved as we reflected on the process of developing complex technologies with our case study groups. The framework therefore crystallises the key lessons that emerged through this project about the development and adoption of complex technologies.

The purpose of the theoretical framework is to improve understanding of the process of participatory technology development that has occurred in each case study group. We have focused on decision support systems as a specific form of complex technology. The theoretical framework shows how this process of participatory DSS development can be examined using concepts from science and technology studies, specifically: **interpretative flexibility**, **technological frames** and **boundary objects**.

Interpretative flexibility means that any object can mean different things to different people, depending on contextual factors (Hess, 1997). When applied to DSSs, the concept of interpretative flexibility emphasises that a DSS will mean different things to the various people involved its development. **Technological frames** are the assumptions, beliefs and expectations that groups of people hold about a specific technology, which in turn influence the design and use of that technology:

> Technological frames provide the goals, the ideas, and the tools needed for action. They guide thinking and interaction. A technological frame offers both the central problems and the related strategies for solving them. (Bijker 1995:191-192)

The concept of **boundary objects** was introduced by Star and Griesemer (1989) in their study of the early years of the Museum of Vertebrate Zoology at the University of California, Berkeley. They define boundary objects as:

> …objects which are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. (Star and Griesemer, 1989:393)

Examples of boundary objects include maps, diagrams, computer models and forecasts (Cash, 2001). The concepts of interpretative flexibility, technological frames and boundary objects can be combined in a theoretical framework (see Figure 1, over page) that clarifies the process of participatory DSS development, and identifies four potential outcomes of this process. The overall structure of Figure 1 was inspired by Pahl-Wostl and Hare's (2004) model of social learning.

Any technology, including a DSS, is conditioned by its external social, cultural, political, economic and biophysical context. The contextual factors that can influence participatory DSS development include macro-level economic factors, such as world markets, through to micro-level social and cultural factors, such as farming traditions and individuals' educational and generational backgrounds and attitudes towards risk (Doorman, 1991).

The main circle in the framework indicates that the concepts of interpretative flexibility and technological frames can help to understand the social context of participatory DSS development. Technological frames may be held in common or differently by different people. Orlikowski and Gash (1994:180) refer to the practice of holding similar technological frames as congruence, namely ‘the alignment of frames on key elements or categories’. Incongruence in technological frames occurs when different people hold differing expectations or assumptions about some important aspects of the technology. Orlikowski and Gash (1994) argue that incongruence in technological frames can create difficulties for the application of a technology, since it can lead to conflicts over the use and value of the technology. Therefore, gaining increasingly congruent technological frames is a key objective of participatory DSS development.

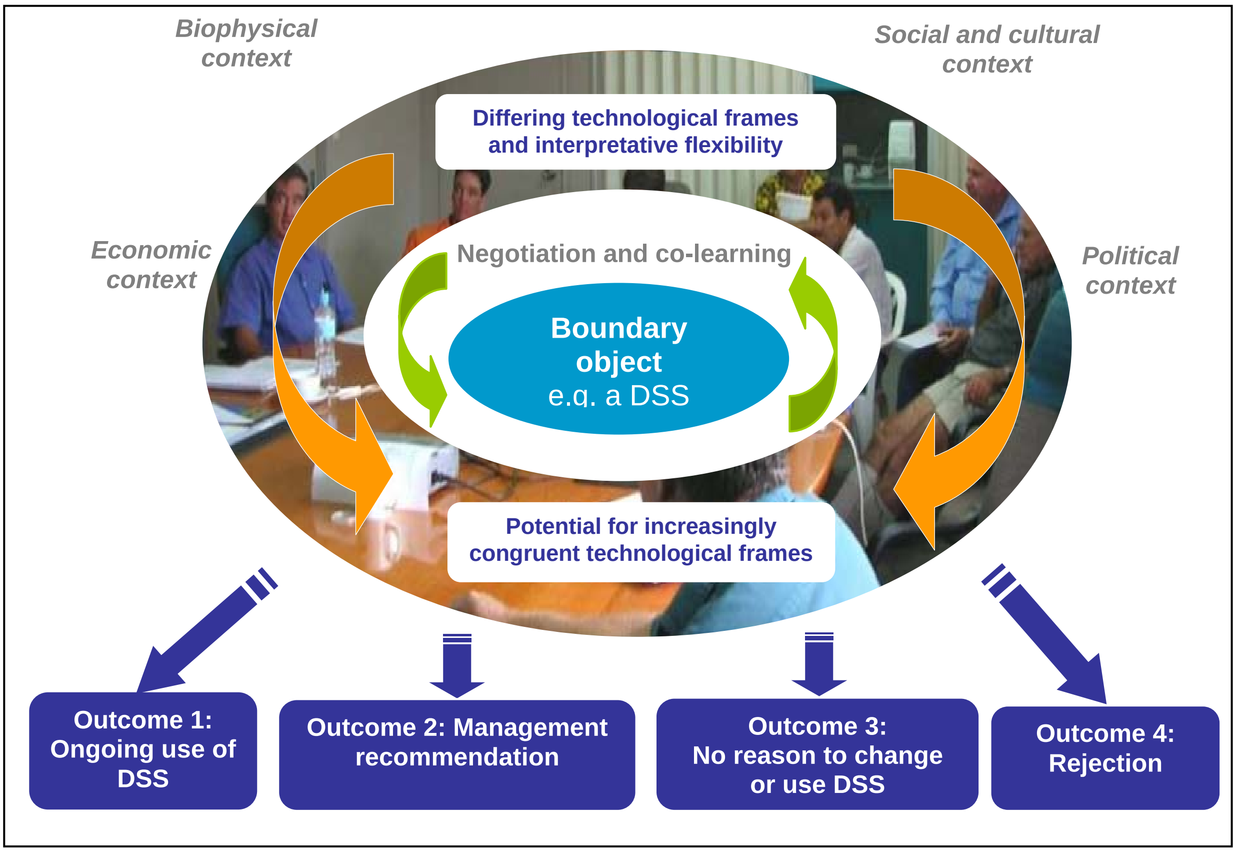

Figure 1: Theoretical framework of the context, processes and outcomes of participatory DSS development

The inner circles in the framework focus on the processes involved in participatory DSS development. By mediating differences and providing a common point of reference, boundary objects facilitate cooperation between different groups of people. Cash (2001) explored the way in which scientific models can act as boundary objects in agricultural extension, highlighting the potential for different kinds of models (including cropping, hydro-geologic and economic models) to serve as boundary objects:

> …models themselves can act as boundary objects, dependent on both the participation of farmers to get inputs that reflect reality and outputs that are useful, as well as on scientists who incorporate basic research on the systems under study and the technical capacity to guide the endeavour. (Cash, 2001:441)

The use of boundary objects can facilitate collaboration between diverse groups of people, which in turn can provide mutually beneficial outcomes.

During participatory DSS development, a DSS may act as a boundary object, creating a temporary bridge that promotes dialogue between the various people involved in its development, while remaining flexible enough to be used by the different parties for their own purposes (Cash, 2001). Through the negotiation, cooperation and co-learning that the DSS-as-boundary object can facilitate, the parties involved in participatory DSS development may arrive at an increasingly shared understanding of the problem, which works towards increasingly congruent technological frames.

The framework also highlights four potential outcomes of participatory DSS development. One outcome may be acceptance by potential users of the value of ongoing use of the DSS. Further cycles of negotiation and co-learning may be necessary to modify the DSS for this routine role (e.g. through making the software more user-friendly). Once the DSS is ready for routine use, emphasis shifts from negotiation and co-learning to adoption of the DSS by farmers and their advisors. This leads to Outcome 1, whereby a DSS may be able to influence farmers' management decisions through its continued role in problem solving. Once developed and proven in this role, the DSS can be distributed through standard diffusion and extension programs.

However, the cycles of negotiation and co-learning that occur through participatory DSS development may lead to a better understanding of the problem and its context. This may allow for simplification of the problem within the specific management and/or biophysical context and result in the discovery of a new and widely applicable management practice with ongoing relevance, which can be applied without ongoing use of the DSS (Outcome 2). This results in the development of a management recommendation, which can be routinely used by farmers and their advisors.

The framework also recognises that through the DSS development process, the parties involved may find that there is no reason to change current practice (Outcome 3). This third outcome may occur because participatory DSS development has led to a better understanding of the problem and acceptance that there is no need or opportunity for changes to the current management practice. Furthermore, participants may ultimately reject the DSS or management recommendation (Outcome 4). For instance, they may believe that the DSS will not provide a sufficient advantage necessary to justify its use or they may not accept the validity of the DSS and its recommendation.

Application of the theoretical framework

In each case study region a mix of growers, extension officers, mill staff and other industry representatives involved in the case study groups were interviewed. These in-depth interviews provided qualitative data that were used to test the validity of the theoretical framework. The experience of the Bundaberg irrigation case study group illustrates how the theoretical framework can be applied to extend understanding of the technology development and adoption process that occurred in each of the case study groups.

A DSS called WaterSense, developed initially as part of the Queensland State Government's Rural Water Use Efficiency Initiative, is designed to enable sugarcane growers to assess when to use their limited water. The project team members responsible for developing the tool worked closely with a small group of growers and extension officers in Bundaberg. This collaboration has been essential for the further development of WaterSense. The interactions through the case study group allowed the scientists, growers and extension officers to explore their different perspectives on irrigation and provided an opportunity to express their technological frames and gain insights into others' frames:

> The right ingredients to have in these sort of projects is respect from the different parties involved so the researcher has a respect that the issues at the grower level or extension level can feed back into the research project and also there's got to be a respect from the grower and the extension officer to say that the research findings are relevant to them as well. …when you respect those parts you have a successful collaborative-type project and I think that project had those ingredients. (Bundaberg, Extension)

Through its development, WaterSense acted as a boundary object, as the scientists, growers and extension officers explored the assumptions of the tool, allowing all participants to gain a better understanding of irrigation and the consequences of different irrigation strategies. As one of the extension officers explained:

> …it was bridging that gap between what was seen to be pretty good science, but making sure that it was paddock useable. [WaterSense]…could've been developed in an office in Townsville and it could've been spat out on a disk, and I don't think anybody would've used it. …the process of developing it and taking the science to the people and the people to the science and bringing the two together so as at the end of the day, something was useful to the grower at his level rather than the scientist at his level, has been the real deal. (Bundaberg, Extension)

The participatory development of WaterSense facilitated a common learning experience, the beginning of making the technological frames more congruent. The collaboration has created strong ownership of WaterSense among the group members:

> …they were committed, they took ownership, and they felt that we valued their input. And I believe also that for me, that these people were all…really contributing, and helping to progress the technology. (Irrigation project team member)

> …the difference was that the growers were being asked to tell the scientists what they didn't know, and that brought growers onboard. What…the growers thought the scientists didn't know, I suppose is a better way of putting it. They were having their point of view listened to. (Bundaberg, Extension)

One of the Bundaberg growers discussed the importance of grower's involvement in the development of WaterSense for gaining growers' confidence in the technology:

> I feel like we were listened to. And I guess if something is going to be accepted, there's got to be some grower input into something like that, because otherwise people are just going to say, 'Here we go again, another hare-brained idea'. …it comes back to the confidence side of things; there was growers involved with it [i.e. the development of WaterSense]. Whereas…sometimes, some ideas are put up and growers may not have had much input into what they wanted, what they expected out of it. I feel we got a fair bit of input into what we expected of it, and yeah, I like it, it's good. (Bundaberg, Grower)

This comment regarding confidence in WaterSense underlines the importance of building trust among the project team, growers and extension officers. Several other participants also discussed the issue of trust:

> In the past, there's been a lot of guesswork in the irrigation side of things. You just think 'This block looks like it might need a drink now', whereas I'm probably taking a bit more

> time and attention now into how much water the crop is using. So yeah, I am starting to trust it [WaterSense] more. I suppose that was the biggest thing, just learning to trust it. (Bundaberg, Grower)
>
> They [the case study group participants] were quite standoffish in the beginning, I felt, and then warmed to and begun to trust. So that's my personal observation. (Bundaberg, Extension)

With the increase in trust and confidence in WaterSense, attention turned to delivering WaterSense over the internet. This suggests that WaterSense could reach Outcome 1 of the framework, whereby the complexity of the irrigation scheduling problem that WaterSense addresses means that it may be routinely used by some growers. In doing so, WaterSense may influence growers' irrigation management decisions by calculating optimum scheduling of irrigation in the context of limited water supply and uncertain rainfall.

The theoretical framework can also be applied to analyse the experiences of the other case study groups. Appendices 1, 2 and 3 provide background details on the seasonal climate forecasting, irrigation and nitrogen management case study groups. Appendix 4 provides an in-depth analysis of how the projects' theoretical framework can be applied to better understand the participatory development process that occurred in these case study groups, using data from interviews with case study group members and the project team.

2. Build understanding and application of complex and emerging technologies

Extensive research has been conducted with industry stakeholders as part of case study groups in Tully, Plane Creek, Bundaberg and northern NSW to build understanding and application of climate forecasting and crop simulation tools. The crop simulation tools were used to improve decision making in relation to irrigation and nutrient management practices.

In terms of climate forecasting, local co-ordinators have been equipped with the skills and technology to continue to produce and deliver climate forecasts to their regions where climate case study groups were conducted. These regions included Tully, Plane Creek and northern NSW. With respect to the application of decision support tools to improve irrigation, an online delivery of irrigation schedules specific to the needs of the farmer and farm has been devised. Moreover, farmers in the irrigation case studies in Plane Creek and Bundaberg have been equipped with the capacity to access and competently interpret outputs. Decision support tools were also used to understand optimal nutrient management practices in relation to fertiliser application rates. In Tully, the only nutrient case study group in this project, participants learnt some fundamentals about applying nutrient management. Specifically, the key lessons learnt were rules about splitting nitrogen applications.

As noted above, Appendices 1, 2 and 3 provide more details about how understanding and application of climate forecasting and decision support tools to improve irrigation management and nutrient management evolved within the case study groups.

3. Identify pathways that can potentially lead to wider adoption of complex technologies

As discussed above in relation to Objective 1, the theoretical framework developed through this project highlights four potential outcomes of participatory technology development.

These outcomes identify pathways that can potentially lead to the wider adoption of complex technologies. Ongoing use of a complex technology, characterised as Outcome 1 in the framework, is the most obvious pathway for wider adoption. This pathway is most likely to be successful when the complexity of the problem that the technology addresses means that it may be routinely used to help solve a management problem; i.e. optimising management practice. Once developed and proven in this role, the technology can then be distributed through standard diffusion and extension programs, thereby potentially resulting in wider adoption of the technology.

However, Outcome 2 in the framework notes that the participatory technology development process may lead to a better understanding of the problem and its context, which allows for simplification of the problem within the specific management and/or biophysical context. This can result in the development of a simple rule of thumb that can be applied without ongoing use of the technology. It highlights the well recognised trend of industry stakeholders learning and developing their own management practices after using a DSS, either in participation with scientists or by themselves (Hearn and Bange, 2002; Stone and Hochman, 2004; Thorburn et al., 2006). These practices could then be extended to other industry stakeholders using general diffusion and extension processes (Hayman, 2004). The adoption pathway identified by Outcome 2 focuses on achieving impact through practice change, rather than solely being based on the ongoing use of a DSS.

Outcomes 3 and 4 also recognise that the participatory development process does not guarantee wider adoption or impact. Outcome 3 in the framework notes that the participatory DSS development may result in an improved understanding of the problem and acceptance that there is no need or opportunity for changes to the current management practice. Outcome 4 suggests that participants may ultimately reject the complex technology or management recommendation. This may occur if the technology does not provide a sufficient advantage necessary to influence industry practices or if the validity of the technology and its recommendations are not accepted.

Thus, the four outcomes identified in the framework provide a novel approach to identifying and evaluating pathways for adoption of complex technologies.

METHODOLOGY

The methodology that guided project management was based on participatory action research. This methodology ensured that the development of the theoretical framework was embedded within ongoing stakeholder participation, through the case study groups. Thus, project methodology balanced theory development with technology development and evaluation.

Figure 2 provides an overview of the project methodology applied in each case study region, which consisted of a combination of awareness raising, action learning and extension activities. This general approach was then tailored to suit the local context within each case study region and the specific technology being developed with the case study group (see Appendices 1, 2 and 3 and Everingham et al., 2006, in Appendix 6, for further details). The action learning approach that underpinned this methodology involved iterative cycles of planning, acting, observing, reflecting and further planning.

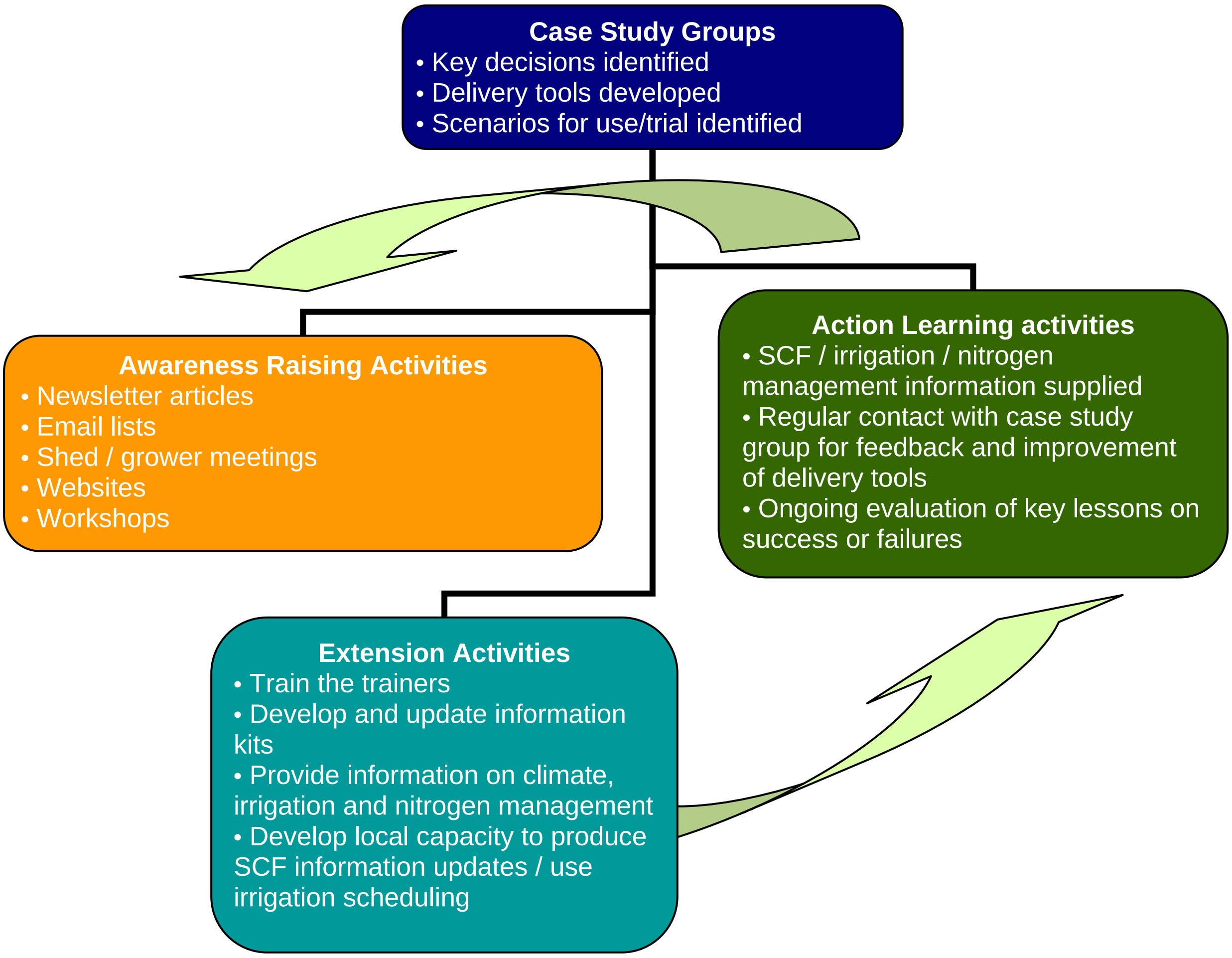

Figure 2: Methodology guiding case study group activities

The development of the theoretical framework and evaluation of the case study group activities occurred in tandem with the case study group activities. The project evaluation was an ongoing process, which supported our action learning approach. Table 1 summarises the evaluation activities that occurred during the project.

Evaluation activities primarily focused on:

- Monitoring and evaluating case study group participants' perceptions of the key lessons they have learnt through being involved in the project; and
- Monitoring and evaluating case study group participants' knowledge, attitudes, skills and aspirations in regard to each of the technologies.

Table 1: Evaluation and 'understanding adoption' activities

Activity	Purpose
Project progress group evaluation sessions	Periodic group evaluation sessions were held in each case study region to obtain feedback from the case study groups on their perceptions of the project progress and any suggestions they have for improvements to the project.
Final group evaluation sessions	The final group evaluation sessions focused on reflecting on the key lessons that case study group participants' have learnt from being involved in the project.
Benchmark case study group interviews: technology specific	In-depth interviews were held with case study group members in the first phase of the project, to benchmark their perceptions of the strengths and limitations of the technologies, the potential impact that the technologies might have, and some of the factors that may influence the impact of these technologies.
Case study group interviews: technology specific	In the final phases of the project, in-depth interviews were conducted with selected case study group participants to explore: • Their experience of being involved in the case study groups; • How their knowledge, attitudes, skills and aspirations in regard to the technologies have changed throughout the project; • Their thoughts on the research approach used in the project; and • Their feedback on the potential for wider use of each of the technologies.
Project team interviews	A series of 'in-house' interviews were held during the project, to reflect on the project team's understanding of the theoretical framework and on the key lessons that emerged through the project.
Case study group surveys: technology specific	A series of surveys were distributed at the case study group meetings to monitor our case study group participants' knowledge, attitudes, skills and aspirations in regard to the technologies.
Wider region surveys	Phone surveys were conducted with people within the Bundaberg and northern NSW case study regions, yet outside of the case study groups, who may have been exposed to project outputs to allow us to further our understanding of complex technology adoption processes.

The data obtained from these evaluation activities enabled us to evaluate the impact of the project, particularly in terms of the learning experiences and capacity building achieved. The final round of case study group interviews involved in-depth interviews with 26 case study group participants across each case study region, to evaluate any changes in case study group participants' knowledge, attitudes, skills and aspirations. Thirteen interviews were conducted face to face and the remaining 14 interviews were conducted over the phone. On average, the interviews went for about 45 minutes. Six project team members were also interviewed about their experiences with collaborating with the case study groups. All of the interviews were recorded with participants' permission and were transcribed to allow the data to be coded for full analysis using QSR NVivo (qualitative data analysis software).

Table 2 shows the number of people interviewed in each case study region for the final round of interviews. In each case study region a mix of growers, extension officers, mill staff and other industry representatives involved in the case study groups were interviewed.

Table 2: Case study group and project team interviews

Group	Number of interviews conducted with growers	Number of interviews conducted with others group members (e.g. Extension Officers, Mill staff)
Tully	4	3
Plane Creek	6	0
Bundaberg	2	4
NSW	4	3
Sub-totals:	16	10
Project team	6	
Total number of final round interviews = 32		

Throughout this report, quotes from these interviews are cited by referring to the participants' case study region and industry sector (e.g. Tully, Grower), to protect the confidentiality of the interviews. Appendix 5 presents the results from the final round of case study group and project team interviews, supplemented by results from the final group evaluations sessions. The data from these interviews were also crucial for testing the theoretical framework (see Appendix 4).

OUTPUTS AND OUTCOMES

Many substantial outputs and outcomes were derived from both the theoretical and technological components of the project. We consider separately the outputs generated from each project component, and itemise separately the outputs generated from the three technological components, which extended to seasonal climate forecasting, irrigation scheduling and nutrient management. We then outline the outcomes that have been achieved over the life of the project.

Outputs

The outputs from the theoretical component of the project are:

- A theoretical framework that extends knowledge of the participatory technology development process and identifies pathways for wider adoption of complex technologies.
- Reports on interviews with growers, extension officers, mill staff and other industry representatives who participated in the seasonal climate forecasting, irrigation and nutrient management case studies.
- Reports on surveys from industry case study members that reflect their personal experiences from being part of the technological case study groups.
- Reports on phone surveys with growers from Bundaberg and northern NSW who were not members of the case study groups, to understand the attitudes of growers towards irrigation scheduling and seasonal climate forecasting within these case study regions.
- A report on the workshop to seek feedback on the theoretical framework developed in this project.

The outputs from the technological components of the project are:

Seasonal Climate Forecasting

- RainForecaster, a computer tool that allows local extension staff to produce and disseminate climate forecasts for their region.
- 'Rules' about climate forecasting, e.g. the types of years when climate forecasts have the greatest skill.

Irrigation Management

- WaterSense, a computer tool operated via the internet that can be accessed by farmers to determine how much water they should apply to their paddocks and when this should be applied.

Nutrient Management

- New understanding of nitrogen management has been documented that details the production and environmental benefits of applying nitrogen in split applications.

Appendices 4, 5 and 7 provide further details on outputs from the theoretical components of this project, while Appendices 1 to 3 provide further details on outputs from the technological components of the project. Appendix 6 contains publications that further support these outputs.

Achieved Outcomes

In addition to these outputs, there are some achieved outcomes that have already benefited the Australian sugar industry.

The achieved outcomes from the theoretical component of the project are:

- Improved knowledge of the participatory development process within the project team.
- Improved understanding amongst the stakeholders and project team of how to engage with industry case study groups on complex scientific issues, through effective participatory processes.
- Improved knowledge and understanding of participatory development and adoption of complex technologies amongst the project team, as well as participants of the workshop conducted to seek feedback on the theoretical framework.

The general achieved outcomes from the technological components of the project are:

- Greater awareness amongst members of the case study groups of improved management skills and practices for growers, harvest operators, millers and industry advisors, based on solutions derived from crop models and climate forecast systems.
- Improved knowledge for case study group members of how their production systems work.
- Improved understanding among case study group members about concepts associated with probabilities.

The specific achieved outcomes from the technological components of the project are:

Seasonal Climate Forecasting

- Greater professional capacity for local climate co-ordinators in Tully, Ingham, Plane Creek and NSW to provide regional climate forecasts and answer questions that newcomers may have about the meaning of the forecasts.
- Skilled industry practitioners who are able to interpret and apply seasonal climate forecasts to reduce the riskiness associated with climate variability.

Irrigation Management

- Skilled extension staff who are able to produce, interpret and deliver knowledge about irrigation scheduling systems to canefarmers.
- Increased awareness and acceptance amongst stakeholders about the need to apply more water earlier in the season.
- Increased understanding amongst stakeholders of how to effectively manage limited water supplies.
- Improved understanding amongst stakeholders and project team about the impact that early stress and late stress has on the sugarcane crop.
- Improved understanding amongst stakeholders and project team about rooting depth and root water extraction.
- Improved understanding amongst stakeholders and project team about contributions of soil and crop to evapotranspiration.

Nutrient Management

- Greater understanding amongst the stakeholders and project team of nitrogen cycling in the wet tropics and the fate of nitrogen applied to sugarcane.
- Greater confidence amongst the stakeholders and project team about capabilities available to model nitrogen cycling in sugarcane production systems.
- Increased understanding amongst the project team about the practical constraints that are associated with widespread adoption of nitrogen splitting.

Impact

The evaluation activities conducted throughout this project provide evidence of the impact that the project has had on the knowledge, attitudes and aspirations of case study group members. The final round of evaluation interviews provide insights into the impact and learnings that emerged from the outputs and outcomes of this project.

Improved industry practices

Many participants commented that they had made changes to their farming practices as a result of being involved in the project. In Tully, many participants report on how they had made changes to their fertiliser management, for instance:

> Like I said, we’ve changed our fertilising practice. We have changed the outlook of how we plan farming. I now realise a tractor and implement is not the only implement. The other one is also the computer, which is the internet. I mean, we’re sourcing information out through the different channels that Yvette showed us. (Tully, Grower)

One Tully participant described the way that his involvement in the group had led him to the idea of ‘weather-proofing’ his farm:

> …basically now, instead of having two farming systems, I've gone to the one, which is aimed at the La Niña. That is just splitting three applications and things like that. …It is structured for the worst scenario. …Mainly because of the autumn predictability [barrier]. …I'm not too sure if I'm unique or something, but I've tried to weatherproof my farm. (Tully, Grower)

In Plane Creek and Bundaberg, some participants commented on how they had improved their irrigation practices, as these growers explain:

> Well probably the main thing is just the irrigation side. You know if…it looks like an El Niño year you can make sure your dams are full before the season starts. That's one way of using it. Also if it's going to be an El Niño or wet year, you're scheduling your harvesting so that the wetter paddocks aren't left to last. You've got a fair possibility of being able to get them off when it's dry. That's another way of using it. (Plane Creek, Grower)

> Just probably…going a little bit tighter to the schedule perhaps. I think it's a matter of…just being confident that you're not going to lose in your production. …it probably reaffirms some of the things that I thought, whereas traditionally in the past, on some of our blocks, I've always gone in and watered too soon. So I found the Water Sense good like that, you could sort of draw down. Because I can get on the computer now and say, yeah, well, today's evaporation rate was such-and-such, and you can sort of watch your water level slide. (Bundaberg, Grower)

In Bundaberg, one participant noted that he would like to be able to use WaterSense for other crops:

> I'm actually trying to use the WaterSense—I've been talking to Steve about it—with my lucerne now, just to try and schedule it. So yeah, it's something we talked about, and he looked into that for me, as into crop factor and water usage. And he said, it's actually very close to cane, so I'm keen to give that a go now too. (Bundaberg, Grower)

The participants from the milling sector both pointed to the way in which WaterSense had improved their ability to prioritise the mill's irrigation:

> Well I guess the most significant thing for us is being confident in the program to be able to allow it to tell us where we begin irrigating after a significant rainfall event. So in other words, that's where for us Water Sense I think, is of greatest value. That's where I see it fitting into out system as in prioritising those blocks that we need to irrigate and I think theoretically it does that quite well. There are issues, nuts and bolts type issues of inputting data and getting the correct data out of it but there have been issues over the time. Just recently we have used it quite effectively after this last rainfall event to help prioritise those blocks that we irrigate first and what order we basically go about our program. (Bundaberg, Mill)

> The priorities of the irrigation. …now I am checking the distribution and the efficiency of this irrigation. Now we can say properly how much water we're putting into irrigation because I have to have this data for the program. (Bundaberg, Mill)

Improved knowledge and confidence

Some participants noted that they now felt more confident in adapting their farming practices to different seasons, for example:

> I'm now confident, more confident for different changing seasons to adapt practices, most definitely. Whereas before this, we all related after the fact, always after the fact, of a chance that we should've done this and should've done that. (Tully, Grower)

> I'm not too sure if it is because of the group by itself, but I've got the water quality work and I'm also associated with Alan Garside…and also this group. Between the three of them and different readings and things like that, well…this season is 11.03: eleventh year in the third month. I'm constantly reviewing it and trying to improve it and basically any scientific information I get, I try and work it into the farming system. I have two or three scenarios and I zero in on those. I amalgamate them or make one and then go ahead until I've got another bit of a challenge and then go again. (Tully, Grower)

Tully participants emphasised that they had learnt the difference between climate and weather:

> When they say climate forecasting, the first perception was weather forecasting. I went there with the total wrong idea; soon modified. …I learnt the difference between weather and climate. When I thought there was no difference at all. …We went there with the perception to understand three days to seven days, weather forecast. Not 12 months, two years or six months ahead, none of that. Then I soon realised that seven days is only just good for five minutes. (Tully, Grower)

> Yeah, from when we first started we were trying to learn about what the climate meant to us. And it wasn't weather, it wasn't weather forecasting. (Tully, Grower)

> …I've learnt that there are differences between climate forecasting and weather forecasting. And neither of them are exact sciences. (Tully, Mill)

Tully participants also learnt about nitrogen application and interactions with soil and weather:

> One of the greatest things that I learnt was with application of nitrogen, fertilisers. …It's a new notion brought to us and we're adapting it. I look at different types. We've got heavy soils, light soils. We've got high country, low country. So it's still a learning process. But it's opened up our eyes a little bit – not opened our eyes, just given us a new vision. (Tully, Grower)

> I've learned how important nitrogen application is, even not enough of, I've learned that. …So I've learned…that there's a right figure in there to put, every year [it] changes, that's all. …. We've just come through a cyclone year, for a lot of rainfall, and that. I've tried different things there. (Tully, Grower)

Some participants pointed to the increased understanding of the limitations of seasonal climate forecasting as their biggest learning, for example:

> …I've realised that the autumn predictability barrier, which I didn't know about… (Tully, Grower)

> As far as climate forecasting is concerned, I gained a better understanding of it and its limitations, and that's how good it could work. (Tully, Extension)

> I think the earliest foray into it [seasonal climate forecasting] didn't really provide us with too many tools because too many of the probabilities were in that 50 to 60 per cent range and weren't really going to affect your decision making. (NSW, Grower)

Another participant noted that he had learnt about the Florida State University model, a new tool for seasonal climate forecasting, which he felt had the potential to be very useful:

> I think like a number of other growers I was fairly sceptical that it was really going to add too much value to our decision-making process. …But I'm really excited about the new FSU model…because I think it seems as if it is going to give us some benefits in forecasting earlier in the year for what is going to happen in the September to December period. If it proves itself over the next few years I think that is going to be a really useful tool for us, both at the mill area level and at the growing level. (NSW, Grower)

In Bundaberg, participants described how they had learnt a lot about irrigation, for instance:

> Soil characteristics, cane physiology, its usage, water application systems and their efficiencies, even just evaporation characteristics, delivery scheduling. …So it was a really big learning curve in terms of irrigation and exposing me to - I call it my virtual enviroscan, WaterSense. (Bundaberg, Grower)

> A lot about irrigation. It's was really useful for me because I have to learn a lot of science…and it was good. …The whole capacity of the science. To really know how much water is required. (Bundaberg, Mill)

One participant noted that he had learnt the importance of using all allocated water in a season:

> The answer to the research question was that the timing issue wasn't as significant as what we first thought. What was significant was that we needed to be in a position to use all of our water. The strategies that we needed to run was more around using the available water that we had whereas previously we thought if we had two megalitres the crop yield was going to be sensitive as to when we used that during the season but the crop actually had a bit of resilience. The main thing was not to get too conservative in your irrigation management in a way that you had water left over at the end of the season and that's when you did suffer you penalty so that was pretty much the answer to the research question… (Bundaberg, Extension)

Improved understanding of participatory approaches

One participant noted that he learnt about working with groups through involvement in the project:

> In terms of the project itself, obviously you picked up some skills there but I think just in dealing with groups and that I got a little bit of out of that. …Yeah, just the different way of getting responses or trying to explore things. (Tully, Extension)

Similarly, another participant noted that involvement in the group had reaffirmed his beliefs about participatory approaches:

> I think my general philosophy with people has been the same, provide a…bigger resource to people that provide support and assistance. …we're all out there in this participatory extension role. If we just stand and deliver and tell people that this is what's right and that's what they should do, I don't think you'd get anywhere. You've got to demonstrate. I rarely ever tell people that this is right and that's wrong. I provide them with information to make their own decisions… (Bundaberg, Extension)

For the project team, one of the changes they identified as a result of their involvement in the project was that they now paid more attention to ensuring that they have a better understanding of what collaborators want and what they understand:

> Yeah, I've been trying to do nothing until – it sort of comes from them. You've got to go to them and say, what do you guys want? …So my idea might be completely wrong or inappropriate for that, but eventually you get panel beaten into something that you and they understand. …Yeah, whatever we do…I'm thinking all the time well, what does it really matter in the final analysis. For example, you could have a very sophisticated model that you've published papers on, but if it's harder to explain than a simple one or less accurate one… You've got to think of what's going to be acceptable, not only in terms of its accuracy but in terms of its understanding. So yeah, it makes a big difference, trying to figure out what people will understand and accept. (Irrigation project team member)

> Yes, you really try to perhaps get a better understanding of what people want, and to be honest, the group themselves didn't understand. The things they said, 'yes, this is an easy change', but when we put them back and said, 'yes, that's a good change', they started backing off, that's because they thought more seriously about it. I suppose it's drilling a bit into what people are really looking for. (Nitrogen management project team member)

One of the key lessons was the importance of appreciating that growers can see things differently than they do and the value of understanding growers' perspectives, for instance:

> I've learned that…you've got to just spend time finding out what the working environment is, what the decision making process is. The farmers' is completely different to yours so you've just got to find out. You can't assume that he knows. You…can't second guess their questions, you've got to find out what they really need to know. How they want that information. (Irrigation project team member)

> …there's also [learnings about] growers responding different ways to what I respond. I guess that's got to do with aims or whatever. That was something that I understood…quite well, because I could see that happening in Tully. I would look at a presentation and think (a) and growers would look at the same presentation and think (b). All those things weren't dynamically opposed, they were different things. (Nitrogen management project team member)

The importance of having ongoing, local co-ordination and support was another key learning:

> The key lesson I learnt, is you must have one person who can help coordinate things in that region. I needed that local coordinator, so that was a good thing. (Seasonal climate forecasting project team member)

> …how important it is to have local support dedicated to continuing the development and use of knowledge-intensive technologies… (Irrigation project team member)

The importance of frequent interactions in participatory research was another lesson from the nitrogen management case study group:

> Ideally, you would like to have more frequent interactions, you would want to put more resources into it and you would want them to put in more resources, or else if those resources weren't available, going to a less interactive model, more a classical outside expert model. (Nitrogen management project team member)

Appendix 5 provides a more detailed analysis of the experiences of those involved in the case study groups. Appendix 7 provides details on the outcomes of the workshop conducted seeking feedback on the theoretical framework.

INTELLECTUAL PROPERTY

The key discovery of the project was the formulation of the theoretical framework to describe the participatory technology development process. This theoretical framework has been widely published and is therefore freely available to the research community to use to help accelerate participatory research and development.

The RainForecaster program has been written in a freeware software package and is therefore freely available.

WaterSense IP is owned by the CRC for Irrigation Futures under CSIRO's agreement with CRCs with which it collaborates. The CRC has undertaken to look for commercial partners who could maintain and further develop WaterSense from an income stream generated by users. This is regarded as a critical step for increasing the impact of this technology for improving water use efficiency and reducing environmental impact in the sugar industry and possible other cropping industries as well.

ENVIRONMENTAL AND SOCIAL IMPACTS

There are a range of potential beneficial environmental and social impacts associated with the implementation of this project. These impacts are outlined below in the section on expected outcomes.

EXPECTED OUTCOMES

The potential of the key findings from this project to contribute to a range of social, economic and environmental outcomes is high.

In addition to the achieved outcomes outlined earlier, the expected outcomes that could benefit the Australian sugar industry in the future include:

Social

- Improved knowledge and understanding of adoption processes of complex technologies in the broader research, development and extension community within and beyond the sugar industry.
- New management skills for growers, harvest operators, millers and industry advisors across the Australian sugar industry, based on solutions derived from crop models and climate forecast systems.
- Improved knowledge for industry members of how their production systems work.

Economic

- Accelerated and increased returns on R&D investments through researchers having a better understanding about the participatory development process of complex technologies, particularly those which are aided by decision support systems.
- Heightened industry competitiveness and profitability at a global scale stemming from modernised management and improved forward planning activities.
- Increased profitability through increased preparedness to adapt to climate variability.
- Increased profitability from the better use of limited water.
- Increased profitability from optimised scheduling for use of limited water.
- Increased yields from full use of allocated water (often not fully used at present).

Environmental

- Reduced wastage of fertiliser, and reduced off-site impacts due to better tactical management practices.
- Improved demonstrable water use efficiency.
- Demonstrated scientific and responsible use of limited water.
- Demonstrated compliance with Department of Natural Resources for submission of Land and Water Management Plans.
- Novel and secure water accounting.

FUTURE RESEARCH NEEDS

A project workshop held in August 2007 supported the need for a theoretical framework that better describes the participatory development process of complex technologies and recommended pathways for further refinement of the framework (see Appendix 7 for the workshop report). Given the favourable review of the framework by expert technology and social science researchers within and external to the sugar industry, future research needs include further development of the framework into an extension process module. This module would serve two distinct purposes:

1. To guide extension practice (even the highly experienced professional extension officers participating in this project refined their knowledge of and engagement with participatory research via learning through this project) and;
2. To inform SRDC investment in sugar extension activities, by providing a set of practice criteria for successful extension, co-learning and adoption.

There should also be broad awareness-raising about the framework to support the application of the extension process module.

The progress or otherwise of the uptake of WaterSense needs to be monitored to assess the impact of the theoretical framework developed in the project. An extension process module could define in more detail the processes of the convergence of technological frames and the development of ‘boundary objects’, to discover the precise nature of adoption barriers. For example, it appears that realistic representations by WaterSense of crop development and soil moisture observations are important in overcoming scepticism about the technology. If that is all that is required to facilitate adoption of WaterSense, then promotion of the technology can be focussed on these relatively simple measurements.

RECOMMENDATIONS

The theoretical framework developed in this project provides a novel approach to understanding participatory technology processes and identifying and evaluating pathways for adoption of complex technologies. The framework also clarifies four potential outcomes of participatory DSS development and suggests that successful DSS development should be defined in terms of practice change, rather than solely being based on the ongoing use of a DSS. The framework contributes to enabling more effective participatory technology development processes by providing scientists and others involved in the development of complex technologies with new conceptual tools to reflect on their practice.

In order to realise its impact, the framework needs to be further developed to more clearly guide interactions between scientists, extension officers and farmers. Future research activities could build on the framework to produce a streamlined and robust process to guide interactions between scientists, extension officers and farmers and maximise the impact of complex and other technologies. This could involve developing new methods for participatory application of complex technologies, which produces better structured interactions, identifies improved outcomes, and provides a more robust conceptual platform for implementation and evaluation of complex technologies.

Comparing and combining this sociological framework with experience of participatory technology development processes in other contexts (e.g. in other industries) could produce a generic and theoretically-informed process for maximising the benefits from participatory researcher-farmer interactions in the sugar industry. This improved process could enhance the efficiency and effectiveness of the participatory interaction around complex technologies, and result in better outcomes for Australian sugarcane, and agriculture more broadly.

We recommend that capacity be built within the sugarcane industry to implement learnings from this framework, to help maximise the impact of complex technologies in the Australian sugarcane industry.

We also recommend that SRDC invest more in projects focusing on understanding of the process of technology development and adoption to maximise ongoing uptake of technology generated by the broader SRDC investment portfolio. The private sector is often more successful in promoting technology than the developers of the technology and we recommend that their methods be analysed in terms of the theoretical framework developed in this project, to enable SRDC-funded research to emulate that private industry success. In the case of ongoing use of DSSs like WaterSense, we envisage a project where consultants could start promoting the use of WaterSense on a trial basis, supported by project funds initially and then by users. We would expect convergence of technological frames of scientists, consultants and users over time such that the science (e.g. measurements of soil moisture for example) and experience of growers and consultants would all agree well enough to underpin the wide scale use of WaterSense for irrigation management, at a relatively small fee.

LIST OF PUBLICATIONS

Book Chapter

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[1] Papers 6 and 11 were also included in a previous SRDC final report (CSE007). Paper 7 was also included in a previous SRDC final report (CSE001).

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APPENDICES

Appendix 1: Background on seasonal climate forecasting component

Appendix 2: Background on irrigation component

Appendix 3: Background on nitrogen management component

Appendix 4: Application of the theoretical framework

Appendix 5: Evaluation of case study group experiences

Appendix 6: Publications

Appendix 7: Workshop Report

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