

**USING SYSTEM DYNAMICS TO EXPLORE THE POOR UPTAKE OF
IRRIGATION SCHEDULING TECHNOLOGIES IN A COMMERCIAL
SUGARCANE COMMUNITY IN SOUTH AFRICA**

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ABSTRACT

Adoption of scientific irrigation scheduling methods has been poor both in South Africa and internationally. Increasingly user friendly and more cost effective tools, the promise of better crop yields, reduced energy costs and the satisfaction of using a scarce water resource wisely have not been enough, collectively, to bring about the much needed wave of adoption. Many studies have set out to understand the cause of non-adoption. These, however, merely reveals a host of variables which make the system complex and overwhelming to comprehend.

A System Dynamics (SD) modelling approach was used to conceptualise the causal agents of the complex system, with the intention to investigate interventions for improving adoption. Irrigation literature was scanned to identify key variables. Narrative data from exploratory interviews with farmers and many informal conversations with extension specialists and colleagues were assimilated to inform model construction. The result was an overarching theory with two separate system dynamics models to explain the adoption process in a farming community.

The classical ‘Diffusion of Innovations’ theory and narrative data from farmers in the case study area suggested that word of mouth was a strong influential force. The first system dynamics model therefore depicts how the balance of positive and negative word of mouth forces will dictate adoption success or failure at the community scale. Key aspects in the model included the number of existing adopters who can give rise to positive word of mouth, and extension support to prevent existing adopters from dis-adopting and giving rise to negative word of mouth.

In the initial stages, when there are few adopters and no word of mouth, the literature and narrative data suggested that leader farmers rely on testing the innovation for themselves to inform the adoption decision. The second system dynamics model therefore aimed to explain how on-farm testing is triggered. The model premise is that a farmer acts when some factor motivates the action. An individual farmer has to accumulate enough motivation to a trigger point, to spark an internal urge to test an innovation. Therefore, the key aspect was to grow perceptions of relative advantage to feed growth of motivation, while simultaneously reducing the perception of risk and uncertainty which drains motivation.

The system dynamics platform contributes to advancing the field of study by extending beyond just listing key adoption variables as important. Instead, adoption success or failure modes were demonstrated to be the effect of a number of causal relationships working together as a collective system.

This modelling work, however, did not aim to derive a recipe or formula with which to increase the adoption of an innovation. The reader should recognise that the world is a complex and dynamic web of relationships. For this reason the recommended way forward is ongoing real world implementation experiments with a suite of interventions, informed by the causal pathways and main simulation results, but taking care to continuously account and correct for signals and feedback from the real world.

DECLARATION

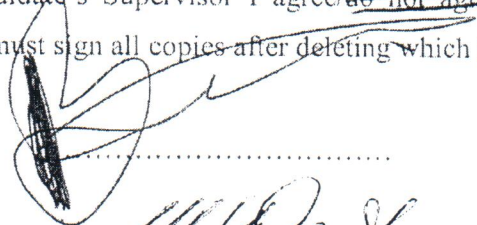
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TABLE OF CONTENTS

	Page
ABSTRACT	II
DECLARATION	IV
ACKNOWLEDGEMENTS	V
TABLE OF CONTENTS	VII
LIST OF FIGURES	IX
LIST OF TABLES	XII
1. INTRODUCTION	1
1.1 Background	1
1.2 The Aim and Objectives of the Research Project	4
1.3 Thesis Structure.....	5
2. A REVIEW OF IRRIGATION SCHEDULING ADOPTION LITERATURE	7
2.1 Irrigation Scheduling.....	7
2.2 Current Status of Adoption of Irrigation Scheduling	10
2.3 Success Factors and Impediments for the Adoption of Irrigation Scheduling....	12
2.4 An Overview of Complex Systems.....	19
2.4.1 Adoption of irrigation scheduling in the context of complex systems....	22
2.5 System Dynamics Modelling	23
2.5.1 Rationale for using system dynamics modelling and novelty of the project.....	23
3. MATERIALS AND METHODS	26
3.1 The Research Context	26
3.2 System Dynamics Model Construction Process.....	29
3.3 Theoretical Framework for Data Elicitation and Subsequent Methodologies	32
3.3.1 Grounded theory.....	34
3.3.2 Drawing from literature.....	35
3.3.3 Semi-structured exploratory interviews to obtain narrative data	35
3.3.4 Observation	39
4. RESULTS (PART 1): EVIDENCE FROM LITERATURE AND NARRATIVE DATA	40
4.1 Important Extracts from Literature	40

4.1.1	Classical diffusion of innovation theory	40
4.1.2	On-farm testing as a process for inducing adoption.....	44
4.2	Narrative Data	46
4.2.1	Narrative data from farmers in the case study area.....	47
4.2.2	Narrative data from other relevant individuals in the SA sugarcane industry.....	50
4.3	Summary	52
5.	RESULTS (PART 2): A WORD OF MOUTH SYSTEM DYNAMICS MODEL	53
5.1	Conceptualisation and Formulation of the Word of Mouth Model.....	53
5.1.1	Preliminary consideration of pathways to improve adoption	60
5.2	Extending the Innovation Diffusion Model to Incorporate Negative Word of Mouth	63
5.3	Model Simulation and Testing (Word of Mouth Model).....	80
5.4	Flaws and Weaknesses in the Word of Mouth Model	92
5.5	Summary and Discussion	94
6.	RESULTS (PART 3): MODELLING ON-FARM TESTING	96
6.1	Conceptualisation and Formulation of On-Farm Testing Model	98
6.2	On-farm Testing Simulation Experiments	110
6.3	Flaws, weaknesses and the simultaneous value of the on-farm testing model .	122
7.	CONCLUSIONS AND RECOMMENDATIONS	125
8.	REFERENCES	130
9.	APPENDIX 1 – MODEL MAPS	141

LIST OF FIGURES

	Page
Figure 1.1	Percentage increase of ESKOM tariff compared to CPI (after ESKOM, 2012)... 3
Figure 1.2	Thesis layout summary 6
Figure 2.1	Illustration of the irrigation soil water balance (after Burt <i>et al.</i> , 1997)..... 8
Figure 2.2	Emphasising the need to understand feedback loops (Morecroft, 2008)..... 21
Figure 2.3	A lack of systemic thinking (Morecroft, 2008)..... 22
Figure 3.1	Depicting SA sugarcane industry and the case study area..... 27
Figure 3.2	A depiction of iterative model construction stimulating experimental learning in both the virtual and real world, after Sterman (2000)..... 31
Figure 3.3	Decreasing information content in moving from mental to written to numerical data bases (Forrester, 1992) 32
Figure 3.4	Iceberg analogy to depict the strength and subsequent leverage of mental databases (Meadows, 2015, after Senge <i>et al.</i> , 2008)..... 33
Figure 4.1	Illustration of the process and key influences in classical diffusion of innovation theory (Stevens, 2006, following Rogers, 2003) 42
Figure 4.2	Adopter categories according to speed of adoption (following Rogers, 2003) .. 43
Figure 5.1	Illustrating the flow of farmers through the stages towards adoption..... 54
Figure 5.2	Current distribution of farmers in the Pongola Mill supply area 54
Figure 5.3	Depiction of boundary formulation omitting “mass media” from model..... 55
Figure 5.4	Formulating the “adoption rate” 56
Figure 5.5	Formulating the “adoption fraction” 57
Figure 5.6	Stock and flow chain with word of mouth and saturation feedback loops 58
Figure 5.7	Simulated baseline results 59
Figure 5.8	Model structure incorporating the “effect of a priority change” 62
Figure 5.9	Improved speed of adoption due to priority change 63
Figure 5.10	Introducing dis-adoption 65
Figure 5.11	Introducing the origins of the “effect of negative word of mouth” 66
Figure 5.12	Illustrating the structural entry point for the “effect of negative word of mouth” 67
Figure 5.13	Recirculating farmers from negatively inclined stocks back to neutral..... 70
Figure 5.14	Causal variables contributing to the “dis-adoption fraction” 71

Figure 5.15	Non-linear graphical relationships between “failure” and the number of “adopters”	73
Figure 5.16	Illustrating the causal variables that inform “failure”, “expectation of failure” and “mismatched expectations”	75
Figure 5.17	Causal relationship for “mismatched expectations”	76
Figure 5.18	Effect of “negative word of mouth” feeding back to contribute to dis-adoption	77
Figure 5.19	Introducing extension support to eliminate a portion of failure.....	78
Figure 5.20	Summary of causal forces in the word of mouth model	79
Figure 5.21	Simulation results associated with a priority change only (Category 1: Table 5.2)	83
Figure 5.22	Simulation results when selected percentage of failure was eliminated by extension support (Category 2: Table 5.2).....	86
Figure 5.23	Simulation results for maximum priority and varied levels of eliminating dis-adoption (Category 3: Table 5.2)	90
Figure 5.24	Summary of the relative strength of the causal forces when number of existing adopters is low	95
Figure 6.1	Conceptual link between word of mouth and on-farm testing in a farming community	97
Figure 6.2	Traditional extension approach to increase adoption by promoting the benefits (relative advantage) of a BMP	99
Figure 6.3	The drainage flow “losing motivation” which arises from “perception of risk and uncertainty”	101
Figure 6.4	Explicit representation of different knowledge stocks.....	103
Figure 6.5	Modelling the ability to apportion the effort required to grow the respective knowledge stocks	104
Figure 6.6	Illustrating the multiple pathways available to stimulate “learning experiences”	105
Figure 6.7	A causal link between the “perception of risk and uncertainty” and “one on one extension” activity	106
Figure 6.8	A causal pathway for reducing the “perception of risk and uncertainty”	107
Figure 6.9	The structural layout of the on-farm testing model.....	108
Figure 6.10	Simulation results for scenario 1 (Reference mode: non-adoption)	117
Figure 6.11	Simulation results for scenario 2 (A more aggressive extension strategy)	118

Figure 6.12	Simulation results for scenario 3 (A more aggressive and focused extension strategy).....	121
Figure 9.1	Word of mouth model map	142
Figure 9.2	On-farm testing model map	143

LIST OF TABLES

	Page
Table 2.1 An overview of irrigation scheduling tools and approaches used in South Africa (after Annandale <i>et al.</i> , 2011).....	9
Table 2.2 A summary of influential themes which recur in the irrigation scheduling adoption literature.....	17
Table 2.3 Inventory of the factors influencing adoption of irrigation scheduling.....	18
Table 3.1 Tabulating the presence of extension services in Pongola	28
Table 3.2 The system dynamics modelling process across the classic literature, after Luna-Reyes and Andersen (2003)	29
Table 3.3 Summary of the flexible structure used for exploratory interviews with farmers.	36
Table 3.4 Typical questions posed to extension specialists in the exploratory interviews ...	38
Table 5.1 Initial condition, default values and the variable range for selected model variables.....	80
Table 5.2 Summary of simulation inputs/scenarios	81
Table 6.1 Initial condition, default values and the variable range for on-farm testing model	111
Table 6.2 Summary of inputs used for simulation experiments	112

1. INTRODUCTION

In this thesis, the problem of poor adoption of irrigation scheduling innovations amongst sugarcane farmers is being studied. Irrigation scheduling is an essential practice for the efficient and effective use of a precious and limited water resource. The literature confirms that the problem is neither confined to sugarcane nor South Africa. Poor adoption of irrigation scheduling innovations is a worldwide phenomenon. In this chapter, the importance of water and the problem of poor adoption of irrigation scheduling are introduced, followed by the presentation of the research aim, objectives and a brief description of the thesis structure as a road map for the rest of the document. The background information presented below portrays the status of water in South Africa and the role of irrigators.

1.1 Background

South Africa is a semi-arid and water scarce country. The mean annual precipitation in South Africa is 450 mm, well below the world's average of 860 mm (NWRS, 2012). In addition, the rainfall in South Africa is unevenly distributed and seasonally irregular in occurrence (Perret, 2002). South Africa was ranked as the 30th driest country in the world (NWRS, 2012). To give an indication of the aridity, consider that the largest river in South Africa, the Orange River, carries 10 times less water than the Zambezi River and 100 times less than the Congo (NWRS, 2012). The opportunities to develop new water resources via the building of infrastructure are limited and, following global trends, attention has shifted to using the existing resources more effectively and efficiently (van der Merwe, 2008). To further exacerbate the situation, rapid population growth and the associated increase in demand for food (Wallace, 2000), coupled with the drive for economic growth and job creation, have escalated the pressure on water resources. Apart from agriculture and the growing awareness of environmental needs, especially in the context of climate change (Benhin, 2006), the mining, industrial and housing sectors are all dependent on water for growth and expansion (Nieuwoudt and Backeberg, 2011).

A total of 62% of surface and groundwater resources are allocated to the irrigation sector in South Africa (NWRS, 2004). As a result of competition from other sectors, the irrigated agricultural sector, being the largest water user, has come under increasing pressure to justify the large allocations of water use. The end users (irrigators), however, have not all taken heed

of the forthcoming crisis. While it appears that the technology, knowledge and institutional arrangements to manage and utilise water efficiently are readily available (Backeberg, 2005; Backeberg and Sanewe, 2006; Pott *et al.*, 2009), poor irrigation management and performance prevails at all levels (Murray-Rust and Snellen; 1993; Reinders, 2001 and Stevens *et al.*; 2005 and Stevens; 2006).

Over-irrigation, resulting in runoff and deep drainage, are associated with the erosion of top soil and the leaching of salts and agricultural fertilisers (van der Laan *et al.*, 2011). The return flows from agricultural land contribute to the degradation of water quality and eutrophication, which has direct implications on water availability for downstream users (van der Laan *et al.*, 2011). Apart from using a large portion of the available water resources, irrigators are hence also viewed as contributors to polluting the resource.

Furthermore, the accruing pressure for irrigators to use water more efficiently expands beyond the realm of sustainable, efficient and equitable use of a limited water resource. Modernisation of irrigation systems in South Africa, and worldwide, has increased the dependency on electrical energy (Rocamora *et al.*, 2013). Currently, the use of water in irrigation is invariably linked to electricity use. Similar to water, however, there is a growing imbalance between the supply and demand of electrical energy in South Africa (Inglesi, 2010). The country's only service provider (ESKOM) has called for a 10% reduction in energy use across all sectors, including irrigation. To compound matters further, the electricity tariffs over the last 5 years have increased at an alarming rate. As shown in Figure 1.1, the electricity tariff has increased by 27%, 31%, 25%, 26% and 16% in the past five years. In some instances, the electricity increase amounted to five times higher than the corresponding Consumer Price Index (CPI).

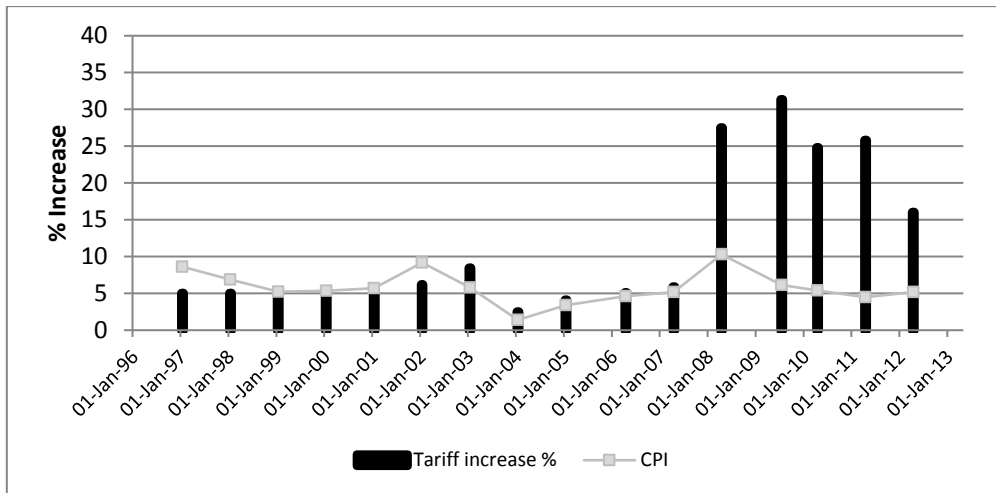


Figure 1.1 Percentage increase of ESKOM tariff compared to CPI (after ESKOM, 2012)

In the context of limited water resources, electricity demand management and financial constraints, margins for error for irrigators are smaller. The survival and prosperity of the irrigation sector appears to hinge on uptake and adoption of technology and best management practices (BMPs) (Backeberg and Sanewe, 2006). Both local and international literature, however, suggest that advances in irrigation scheduling was not widely adopted. The results for a number of irrigation scheduling adoption studies are presented in Section 2.2. For example, Lieb *et al.* (2002), Stevens (2006) and Stirzaker (2006) reported that the number of farmers scheduling irrigation was only in the region of 18 - 23% in Washington (USA), South Africa and Australia. Despite the investment in resources and subsequent research successes, farmers are still not making use of recommended practices and technologies (Annandale *et al.*, 2011).

It is evident that there are many factors and stakeholders that influence the adoption process. The range of factors influencing adoption was reported to include the farm attributes (farm size and value of crops) (Stevens, 2006), the farmer's characteristic traits (such as age or education) (Bjornlund *et al.*, 2009) and the provision or absence of support and training (Leib *et al.*, 2002). Stirzaker (2006) provided a list of barriers to adoption, which also included issues such as complexity and uncertainty associated with some tools. The theme of irrigation management cuts across the social, engineering, economic and environmental disciplines (Stevens, 2006; Stirzaker, 2006 and Baumgart-Getz *et al.*, 2012). These factors and their interactions can vary over time and space, creating uncertainty (Pollard *et al.*, 2011). The adoption of irrigation scheduling appeared to be complex.

Complexity arises from a large number of interacting and interdependent factors (Pannell, 1999). The relationships and connectivity between these factors are not always visible or easy to describe, giving complex systems the defining characteristic trait of being unpredictable (Pollard *et al.*, 2011). The degree of complexity is attributed to the quantity, quality and resultant behaviour of the web of relationships (Richardson, 1994).

Past studies on irrigation scheduling adoption fail to engage adequately with the complexity. The novelty in this thesis emerges from engaging with the complexity via the use of system dynamics models. System dynamics modelling is a technique for framing, describing, understanding and communicating complex problems or processes (Forrester, 1991). Emphasis is placed on capturing the internal forces which result from either the context or decision rules/policies that drive action (Richardson, 2011). More information on system dynamics models is presented in Section 2.5.

1.2 The Aim and Objectives of the Research Project

In the context of irrigation scheduling in the case study area, the aim of this project was to apply system dynamics modelling to assimilate the socio-technical factors that impact on the spread of innovations, so that recommendations for improving adoption of irrigation scheduling can be made.

The research project objectives were to:

- Conduct literature reviews on adoption of irrigation scheduling, complex systems, system dynamics modelling, innovation diffusion theory and relevant theory necessary for meaningful planning and design of stakeholder interactions and data extraction processes.
- Identify and map key factors and points of leverage which influence irrigation scheduling adoption in the South African sugarcane context.
- Develop, test and apply system dynamics simulation models which represents the connectivity and behaviour of the socio-technical system related to adoption of irrigation scheduling.
- Provide recommendations for improvement in irrigation scheduling adoption based on simulation modelling experiments.

Sterman (2000) suggested that, in application of system dynamics, the model building exercise should target a difficulty, a problem which keeps people up at night. The model audience should be those whose behaviour must change for the problem to be solved. It was clear that the behaviour of irrigators must change to correct the problem of not using water wisely by not adopting irrigation scheduling tools. However, there is also evidence to suggest that the lack of adoption is not viewed as a problem by the farmers. It is not something that keeps farmers up at night. Hence farmers have no reason to alter their behaviour. Irrigation water use efficiency was a priority for the custodians of water (the government, scientists and the public at large), not necessarily for individual growers. The irrigators own the problem but do not view it as a difficulty.

With the above in mind, the target audience for the model was set as the agents of technology transfer (Extension Specialists) and designers of the processes/events to stimulate innovation diffusion (Knowledge Management Unit) within the SA sugarcane industry. As custodians of the technology transfer process, knowledge management and extension can both take ownership of the problem situation and have the ability to influence the behaviour of farmers to correct the problem situation. Hence, interaction with the farmers was considered important to gain insight about the realities of irrigation scheduling adoption, but the main participatory stakeholders for model construction, testing and learning from simulation experiments were SASRI's extension specialists and the knowledge management unit. For this reason, demonstrating a statistical improvement in the adoption of irrigation scheduling was considered out of scope for this project. It was assumed that extension and the knowledge management unit would require time, after the completion of this project, to implement the findings of this study before improvements in the adoption of irrigation scheduling in the case study area became visible.

1.3 Thesis Structure

The thesis layout is summarised in Figure 1.3 below. The relevant literature is reviewed in Chapter 2. Initially, irrigation scheduling is defined, followed by a presentation of the various tools, methods and technologies available for irrigation scheduling. The current status of irrigation scheduling is then reviewed, followed by the various reasons cited for adoption success and failure. In light of the lack of adoption success and the array of explanatory

variables and theories, the problem was next introduced as a complex problem. An overview of complex systems is provided, followed by a justification for the use of system dynamics models in this study.

The materials and methods presented in Chapter 3 include an introduction to the background context and case study area, the process for constructing a system dynamics model, followed by the theoretical framework and data elicitation techniques used in this study. Emerging from a common methodology, the results are presented systematically and logically in 3 parts. In Chapter 4, results part 1, key evidence from literature and narrative data which was especially instrumental in the conceptualisation and shaping of causal themes is presented. The first part of the results, presented in Chapter 4, therefore, addresses the second research objective, i.e. to identify and map key factors in the adoption of irrigation scheduling. In the subsequent results Chapters 5 and 6, the causal themes which emerged in Chapter 4, ‘peer word of mouth’ and ‘learning and experience from on-farm testing’, are explored through the formulation of system dynamics models followed by further learning from model simulation experiments. The value, novelty, summary of outcomes, conclusions and recommendations of the study is presented in the Conclusion and Recommendations Chapter.

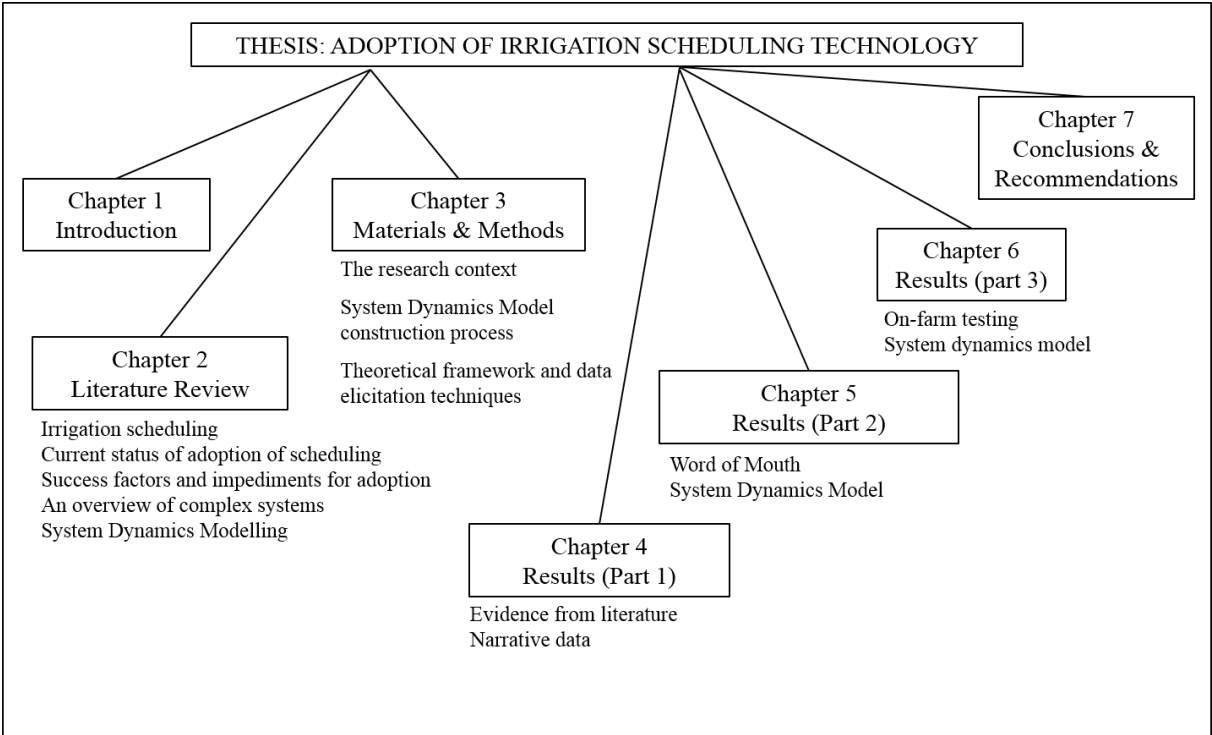


Figure 1.2 Thesis layout summary

2. A REVIEW OF IRRIGATION SCHEDULING ADOPTION LITERATURE

In this chapter the literature is reviewed for multiple reasons. Over and above presenting an overview of irrigation scheduling, Section 2.1 also aims to demonstrate that a wide range of irrigation scheduling tools are readily available to farmers. In Sections 2.2 and 2.3, literature on improving the adoption of irrigation scheduling was scanned in order to gauge current adoption levels and to detect factors which were most crucial for influencing adoption. The literature reveals that, globally, levels of adoption are below expectation, and, despite the large investment in research and development, little progress has been achieved. In Section 2.4, an overview of complex systems is presented in order to gain a deeper understanding and appreciation of the complex nature of the adoption problem. Finally, in order to justify the use of system dynamics modelling as a methodology to engage with this specific complex and dynamic problem, literature on system dynamics modelling is reviewed in Section 2.5.

2.1 Irrigation Scheduling

Irrigation scheduling is the process of deciding when and how much water to apply (Pereira, 1999). Poor irrigation scheduling can result in either under-irrigation, leading to crop stress and reduced yields, or over-irrigation which leads to misuse of water and electricity resources, leaching of expensive fertilisers, pollution of water, erosion of top soil and potentially yield reductions from anaerobic soil conditions (Pereira, 1999; English, 2002; Lecler, 2004; Annandale *et al.*, 2011). Scientific or objective scheduling of irrigation applications is therefore an important better management practice (BMP).

The soil-plant-atmosphere continuum, demonstrated in Figure 2.1, helps to understand how irrigation scheduling decisions are taken. Analogous to a bank account, the amount of water in a soil can fluctuate depending on gains or losses. Rainfall and irrigation contribute to gains since they increase the soil water content, while losses occur through transpiration, evaporation, runoff or deep percolation (Burt *et al.*, 1997). For crop production, the availability of soil water in the root zone is critically important (Annandale *et al.*, 2011). The crop, via transpiration, beneficially extracts water out of the soil to allow for photosynthesis and biomass production. If rainfall is inadequate, irrigation is required to refill the soil water reservoir in order to prevent

unnecessary crop stress. If the soil water reservoir is full and irrigation is still applied or rainfall occurs, water is lost through surface runoff or deep percolation beyond the root zone. Since it is difficult to separate the evaporation and transpiration components, they are often combined and referred to as evapotranspiration (ET) (Burt *et al.*, 1997). Deciding when and how much water to apply is therefore a function of the dynamics within the soil-plant-atmosphere continuum (Raine, 1999). The soil water status is a function of the soil water holding characteristics, the prevailing weather conditions and the crop water use characteristics.

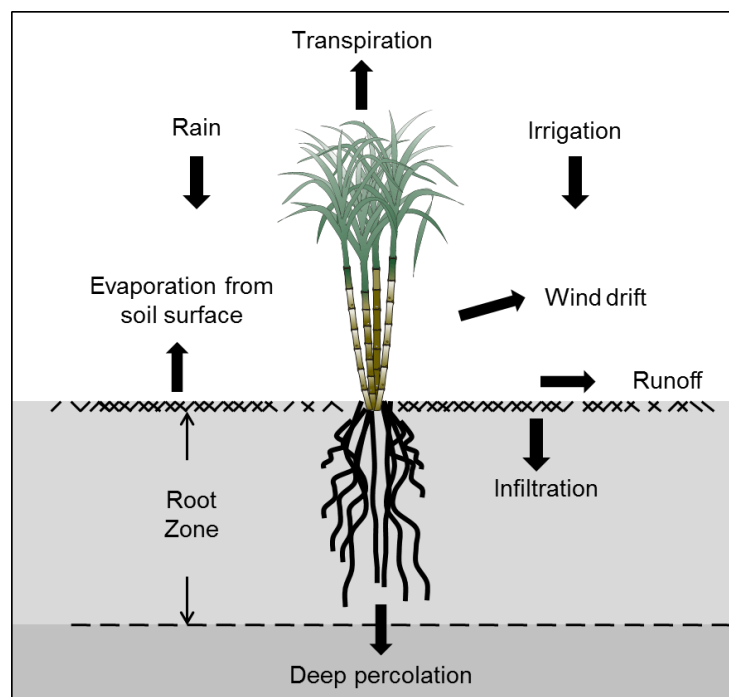


Figure 2.1 Illustration of the irrigation soil water balance (after Burt *et al.*, 1997)

A detailed account of irrigation scheduling tools in South Africa is reported on by Stevens *et al.* (2005). Stevens *et al.* (2005) subdivided irrigation scheduling methods and techniques into the following five groupings; (a) intuition, (b) atmospheric based quantification of evapotranspiration, (c) soil water measurement, (d) plant-based monitoring and (e) integrated soil water balance approaches. The latter includes real time approaches and pre-programmed methods, such as irrigation calendars.

Intuitive scheduling is not scientific. It is either based on traditional practices (e.g. a recipe) used by previous generations or other role players, or it is based on regular observation of the soil, plant and weather conditions together with a basic understanding of the system and accumulated past experiences (Stevens *et al.*, 2005). In the remaining groups, a wide range of

scheduling tools varying in accuracy, cost, simplicity, available support and skill and time requirements are obtainable and can be matched for almost any situation. These include, but are not limited to, computer models and sensors. Computer models aim to estimate irrigation requirements and intervals by modelling the soil water budget and crop water use. Sensors measure the soil moisture status or the response of specific crop parameters to water availability. Table 2.1 provides an overview of the irrigation scheduling tools and approaches available to irrigation managers in South Africa.

Table 2.1 An overview of irrigation scheduling tools and approaches used in South Africa (after Annandale *et al.*, 2011)

Plant based techniques	Leaf water potential (thermocouple psychrometers and various pressure chambers)
Soil Based Techniques	Soil water content (neutron probes, capacitance probes, etc.)
	Soil water potential (tensiometers, watermark and other porous matrix sensors)
	Wetting depth (Full stop wetting front detector)
Atmospheric Based Approaches	A-pan evaporation and crop coefficients (green book method, check book method and pegboard method)
	Computer models of soil water balance (BEWAB, PHUTU, SWB and My Canesim)
	Predetermined irrigation demand calendars derived from computer models

Computing capacity and technology developments have enhanced the accuracy and ease with which scheduling tools can be used (Jensen *et al.*, 2000; Vellidis *et al.*, 2008; Romero *et al.*, 2012). Continuous logging of data, automatic and remote accessing and processing of data, and publishing of data on the internet in an easy to interpret format are some of the examples of technological developments (Charlesworth, 2000; Jensen *et al.*, 2000; Leib *et al.*, 2001; Vellidis *et al.*, 2008). Technology has progressed such that even remote satellite imagery of fields used in conjunction with the energy balance can now provide information on crop water use (Bastiaanssen *et al.*, 2000; Gowda *et al.*, 2008). These types of tools are attractive since the complicated science is hidden and farmers receive the information in a simple, digestible format for easy decision making (Belmonte *et al.*, 2005). For example, the crop stress or ET of a field

can be viewed online in a colour coded map of the farm. Similarly, farmers who subscribe to the Canesim irrigation scheduling service receive short messaging service (SMS) on their cell phones (Singels and Smith, 2006). The SMS informs them to either start, stop or continue irrigating (Singels and Smith, 2006).

The next section reviews the adoption of irrigation scheduling. Local and international literature is cited to indicate levels of success or failure in achieving adoption. The literature was also reviewed to detect factors that were perceived to contribute to either the success or failure in the technology transfer process.

2.2 Current Status of Adoption of Irrigation Scheduling

In South Africa, adoption of irrigation scheduling is, according to researchers, below expectations. Annandale *et al.* (2011) report that the Water Research Commission (WRC) has, over the last 40 years, funded several projects which successfully produced many irrigation scheduling technologies. The PHUTU model (de Jager *et al.*, 1987), BEWAB (Bennie *et al.*, 1988), SWB (Annandale *et al.*, 1999), Canesim (Singels and Smith, 2009) and Wetting Front Detectors (Stirzaker, 2003) are a few examples of research and development successes in South Africa. Annandale *et al.* (2011) report that, while exceptional advancements were realised amongst the scientific research fraternity, transfer of these technologies to farmers was poor. It is argued that the value of research results are not fully realised due to widespread lack of adoption. Stevens (2006) report that less than 18% of irrigators in South Africa make use of scientific irrigation scheduling tools. Olivier and Singels (2004), in an independent survey, report that poor adoption of irrigation scheduling tools was also the case within the sugar industry in South Africa.

Similar to South Africa, the international literature also suggests that poor irrigation scheduling practices still prevail on many farms. In Australia, for example, Car *et al.* (2012) report that Watersense, a tool with proven ability to improve water use efficiency (Inman Bamber *et al.*, 2005), was used by less than a hundred farmers, among thousands. Furthermore, a maximum of 12 users was recorded for any of the 21 irrigation decision support systems operated in Australia (Inman Bamber and Attard, 2005 cited by Car *et al.*, 2012). Stirzaker (2006), based on the Australian agricultural census data, reported that the use of scientific irrigation scheduling methods increased from 13% in 1996 to 23% in 2003. While the increase in adoption

rates was promising, there was still a concern that almost 80% of farmers did not adopt any of the available tools (Stirzaker, 2006). Lieb *et al.* (2002), based on a survey in Washington State in the USA, found that scientific irrigation scheduling was practiced on only 18% of the 858 300 ha of irrigated land. In Canada, based on a survey of 52 100 ha over two irrigation districts, Bjornlund *et al.* (2009) found that less than 30% of the irrigators made use of monitoring instruments, computer, phone, web based programs or private consultants to schedule their irrigation. The survey also indicated that few farmers had plans to do so in the near future (Bjornlund *et al.*, 2009). In a case study in Castilla-La Mancha in central Spain, Ortega *et al.* (2005) and Montoro *et al.* (2011) reported on the performance of an irrigation scheduling service established in 1988. By 2005, Montoro *et al.* (2011) reported that the area serviced expanded to 33 500 ha of a possible 100 000 ha, indicating a degree of success on just more than 33% of the area. Ortega *et al.* (2005) found that approximately 25% of the irrigated area received scheduling advice. The irrigation scheduling service also grew to provide field checks, irrigation monitoring and system performance assessments (Montoro *et al.*, 2011) and, in some instances, customised scheduling advice.

There have been reports of some successes. The most prevalent model in these instances was when an irrigation advisory service was made available to irrigators. The California Irrigation Management Information System (CIMIS) is a prominent example (Ortega *et al.*, 2005). CIMIS was developed in 1982 through a joint research and development project between the University of California and the California Department of Water Resources (CIMIS, 2013). The primary function was to provide, via a network of weather stations, reference evapotranspiration estimates to water agencies, farmers, farmer advisors and irrigation specialists as a source for irrigation scheduling (Eching and Moellenberndt, 2000; Eching, 2002). CIMIS has experienced 20% year on year growth since 1985 and it is estimated that over 15 000 farmers receive CIMIS related irrigation scheduling advice (Eching, 2002). Subsequently, the CIMIS activities expanded to include research initiatives to provide, for example, crop coefficients. Many value adding agencies have also collaborated with CIMIS to provide access to irrigation scheduling software, specialist advisory services, training workshops and evaluation of irrigation systems with mobile irrigation labs (Eching and Moellenberndt, 2000; Eching, 2002). By adopting and adapting to the CIMIS model, many other irrigation advisory services have been established in the USA. The University of Florida, University of Georgia, Texas Cooperative Extension, Utah State University Extension and the University of Minnesota are a few examples (Ortega *et al.*, 2005 citing Smith and Munoz, 2002).

The incentives for adoption of irrigation scheduling include better efficiency in the use of water and electricity resources and associated cost benefits, higher crop yields and reduced leaching of expensive fertilisers.

The lack of adoption in the presence of these clear incentives and substantial investment and research success is confusing. Why are growers not adopting scheduling despite the presence of many benefits? This question can be described as an ambiguity. “When an unsolved difficulty seems to have a clear solution that is not getting implemented there must be an ambiguity. An ambiguity is defined as a puzzle, or a question, whose answer will help to understand the cause and possible solutions to a difficulty” (Mashayekhi and Ghili, 2012). The identification, raising and answering of ambiguities depicts the iterative process for problem definition and hypothesis testing (Mashayekhi and Ghili, 2012). In the context of BMP adoption, it is logical to conclude that despite the many incentives there must still be some factors which obstruct adoption. As suggested by Mashayekhi and Ghili (2012), uncovering and developing a deeper understanding of the ambiguities could be the key to improving the adoption of irrigation scheduling. In the next section, past studies documented in the literature are drawn from in order to detect key factors which may hinder or accelerate the uptake of irrigation scheduling.

2.3 Success Factors and Impediments for the Adoption of Irrigation Scheduling

The most comprehensive study on adoption in the irrigation sector in South Africa was completed by Stevens (2006) who, in a doctoral study, focused on the adoption of scientific/objective irrigation scheduling. Stevens (2006) conducted semi-structured interviews with irrigation professionals and a qualitative survey of large and small scale growers on 32 irrigation schemes. Stevens (2006) indicated that a combination of technical and human socio-economic issues influenced adoption rates. Examples of technical issues, usually labelled as the hard issues, included:

- (a) the status of current farm technology level,
- (b) size of the farm,
- (c) value of crops,
- (d) crop quality,
- (e) reliability and flexibility of bulk water supply and infield infrastructure, and

(f) the potential to reduce electricity costs and fertiliser leaching, amongst others.

The human socio-economic issues, typically labelled as soft issues, are as follows:

- (a) scientists often work in isolation and fail to understand the world view and complex reality under which farmers operate (Stevens, 2006; citing Vanclay, 2004) resulting in incompatible tools and misaligned recommendations,
- (b) situational variation relating to perceived and real benefits/risks,
- (c) incorrect extension packaging relating to either too much or inappropriate information (information dazzle), or insufficient information, and
- (d) the perceived investment of effort, time and resources required.

Stevens (2006) emphasised that the previously neglected softer issues have a strong influence and an enabling environment for scientists, extension specialists and farmers to network and co-learn was required. This was corroborated by Annandale *et al.* (2011) who proposed that adaptive and experiential learning initiatives are required, amongst others, to further improve the adoption of better irrigation management practices. Olivier and Singels (2004) found irrigation scheduling decision support programs to be impractical and too complicated to be useful. In order to address the shortcomings of decision support programs, Singels (2007) discusses the need for South African farmers' participation in the design of a decision support program.

In the USA, Baumgart-Getz *et al.* (2012) conducted a meta-analysis, on 42 carefully selected papers, in order to identify the variables which have the largest impact on adoption. Variables were divided into 3 categories namely, capacity, attitude and environmental awareness. In the capacity category farm size, age, extension training, capital, percentage income from farming and tenure are positively related to adoption. Farming experience for example, was not found to be a significant driver. The meta-analysis also suggest that social factors, within the attitude and environmental awareness categories, only have a small influence on adoption and use of such factors in studies must define a clear connection to BMP adoption (Baumgart-Getz *et al.*, 2012). For example, perceived risk was included as an attitude variable. A farmer's willingness to take risks was hypothesised to have a positive effect on adoption. The study indicates that perceived risk as an influencing factor reduces over time. As innovations become more widely used, the perceived risk appears to diminish. Factors having the largest influence on adoption were listed as: access to and quality of information, financial capacity and being connected to an agency or local network of farmers or watershed groups (Baumgart-Getz *et al.*, 2012).

In a case study context, Bjornland *et al.* (2009), citing Stephenson (2003), state that farmers who adopt innovations at an early stage tend to be younger, more educated and more cosmopolitan, have higher incomes, larger farm operations and are more reliant on primary sources of information. Furthermore, adoption is driven by economic factors if an innovation is easy to implement and has demonstrable benefits. If the innovation, however, required considerable new skills, adoption is driven by sociological factors (Bjornland *et al.*, 2009; citing Morrison, 2005).

In a comprehensive study in Australia, Stirzaker (2006) proposed 7 obstacles to adoption. These are:

- an entrenched culture,
- farmers don't see the importance,
- the investment does not pay,
- BMPs are hard to implement,
- there is too much complexity and uncertainty,
- different goals of science versus farmers' perspectives, and
- the wrong extension model.

In a later publication, Stirzaker *et al.* (2010), expanded on the mismatch between the perspective and goals of scientists and farmers. Scientists tend to concern themselves within a framework of accuracy while farmers are more interested in aspects such as the ability to test a tool or BMP on a smaller scale, or the compatibility with current practice and the management of risk. Leib *et al.* (2002), Ortega *et al.* (2005), Bjornland *et al.* (2009) and Montoro *et al.* (2011) all suggest that farmers adopt irrigation scheduling to improve crop yield, crop quality or profitability, not necessarily to use water more efficiently. The efficient use of water was ranked as a low priority. In some instances growers would only consider adopting innovations if it helped to reduce the amount of time spent on water management, thereby freeing up time to spend on other activities (Kaine *et al.*, 2005). Water as a low priority does not hinder or prevent adoption, but adoption is more likely to occur if water was considered a high priority. Ortega *et al.* (2005) indicated that water does become a high priority when supply is low or when irrigation costs are high. Adoption of innovations was higher in these instances to secure water supply or reduce costs.

Faber and Snyder (1990) reported on an array of factors which were positively associated with adoption of scheduling with Evapotranspiration (ET) data from the California Irrigation Management Information System (CIMIS). The array of factors includes:

- Larger and more diversified farms, growing more than four different types of crops, were more prevalent in the use of ET data,
- pressurised irrigation systems were positively related to ET based scheduling,
- larger farming operations were more likely to adopt ET based scheduling,
- farmers who adopted other innovations (such as minimum tillage or irrigation improvements within the previous 10 years) were more willing to try ET based scheduling methods, and
- regions with extension farm advisor activity and a history of promotion and research, competitive grower population and many progressive agricultural leaders also correlated with a high percentage of schedulers.

Linked to extension and the provision of advisory services, Shearer and Vomocil (1981), state that for adoption of fertiliser and weed control practices, sustained and concentrated support was required from both industry and educational institutions to accomplish market transformation. Leib *et al.* (2002) argues that a similar paradigm for the provision of support services is required for irrigation scheduling.

Ortega *et al.* (2005), in the context of external irrigation advisory services, emphasised the importance of coordination with farmers to ensure that they participated in solutions and provided valuable feedback. Scientists need to better understand farmers requirements and the constraints under which they operate (Stevens, 2006; Stirzaker, 2006 and Annandale, 2011; citing Vanclay, 2004). Irrigation advisors must take cognisance of local experience and the divergence between research results and farmers' practices (Ortega *et al.*, 2005). In the Australian sugar industry, Juffs *et al.* (2004), Webb *et al.* (2006), Everingham *et al.* (2006), Jakku *et al.* (2007) and Thorburn *et al.* (2011) have all, in the past decade, worked on improving the uptake of irrigation technologies and adoption of BMPs through participatory research approaches. These initiatives aimed to promote co-learning or networking amongst scientists, extension and farmers to support and enable a better understanding of the respective realities.

Many similar publications, focusing on participatory modelling (Jakku and Thorburn, 2010; Smajgl, 2010; Voinov and Bousquet, 2010; Hochman and Carberry, 2011), reveal a trend towards discovering the influence of human socio-economic factors on productivity in agriculture. These softer and more subtle human issues have become so prominent that the *Agricultural Systems Journal* devoted an entire issue to address the subject of poor adoption of decision support systems (Everingham *et al.*, 2006; citing McCown, 2002).

As indicated in Table 2.2 numerous studies were focused on the adoption of irrigation scheduling innovations. Scientists from many disciplines, e.g. Extension (Stevens, 2006), Social Science (Jakku *et al.*, 2007), Agronomy (Stirzaker, 2006; Stirzaker *et al.*, 2010), Crop Modelling (Singels, 2007) and Irrigation engineering (Eching, 2002; Ortega *et al.*, 2005) have conducted a reasonable amount of work and have provided an array of factors to explain the success factors and impediments to the adoption of irrigation BMPs. The wide array of factors have been categorised into emergent themes, namely, (a) Farmer traits, (b) BMP attributes (c) Support and training (e) Economic, (f) Social, (d) Physical and (e) the Priority ranking of water. Table 2.2 summarises how frequently the emergent themes appear in the reviewed literature.

Table 2.2 A summary of influential themes which recur in the irrigation scheduling adoption literature

No	Reference	Farmer traits	BMP attributes	Support & training	Economic	Social	Physical	Priority ranking of water			Country
								Low	Mediu	High	
1	Whittenbury and Davidson (2010)		√		√	√		√			Australia
2	van der Merwe (2013)		√		√	√	√				South Africa
3	Baumgart-Getz <i>et al.</i> (2012)	√		√	√	√				√	USA
4	Car <i>et al.</i> (2012)	√	√								Australia
5	Annandale <i>et al.</i> (2011)		√	√							South Africa
6	Hochman and Carberry (2011)		√	√		√					Australia
7	Montoro <i>et al.</i> (2011).			√	√			√			Spain
8	Stirzaker <i>et al.</i> (2010)		√	√		√					South Africa
9	Bjornlund <i>et al.</i> (2009)		√		√		√	√			Canada
10	Boland <i>et al.</i> (2006)			√			√	√			Australia
11	Stirzaker (2006)		√	√	√	√	√				Australia
12	Stevens (2006)	√	√	√	√	√	√				South Africa
13	Kaine <i>et al.</i> (2005)		√	√			√	√			Australia
14	Ortega <i>et al.</i> (2005)			√	√			√			Spain
15	Vanclay (2004)	√	√	√	√	√	√				Australia
16	Eching (2002)			√	√						USA
17	Leib <i>et al.</i> (2002)	√		√	√		√	√			USA
18	Smith and Munoz (2002)	√	√	√	√						Global (ICID)
19	Burton <i>et al.</i> (1999)			√	√						Global
20	Raine <i>et al.</i> (1999)	√	√	√	√	√	√				Australia
21	Faber and Snyder (1990)	√		√	√		√				USA
		Total	8	13	17	15	9	10	7	0	1
		%	38	62	81	71	43	48	33	0	0.4

In Table 2.2, 81 % of the authors cited, considered training and support as important factors in the adoption of irrigation scheduling. Economics and ‘the attributes of the irrigation scheduling

innovations' were also considered influential by 71 % and 62 % of the authors, respectively. Table 2.3 presents an inventory of factors cited in this literature review, which were deemed to be influential in the adoption of irrigation scheduling. Following on from Table 2.2, the factors in Table 2.3 were also categorised under the themes; farmer traits, innovation attributes, support and training, and the economic-, social- and physical-landscape.

Table 2.3 Inventory of the factors influencing adoption of irrigation scheduling

No	Factor	Promotes or associated with better adoption	Inhibits or associated with poor adoption
Farmer Traits			
1	Age of farmers	Younger	Older
2	Education	Tertiary education, computer literacy	Not computer literate
3	Social connectedness	More connected	Less connected
4	Adopted other innovations	Forward thinker	Cultured
Innovation attributes			
5	Tools are complex	Less complex	More complex
6	Not easy to implement	Practical	Impractical
7	Relative advantage	Yield gain, securing water, reduce costs	
8	Incompatible tools	Easy to align with farm culture, operations, or value system	Not easy to align with farm culture, operations, or value system
9	Demonstrable benefits	Easy to demonstrate and view results	Not easy to view results
10	Ability to test on small scale	Low risk	High risk
11	Reliability	More reliable product service	Less reliable
12	Affordability	Cheaper	Expensive
13	Accuracy	More accurate	Less accurate
Support and Training			
14	Extension	More contact time	Less contact time
15	Access to information	Easy access	Difficult to access
16	Quality of information	Correct information	Incorrect information
17	Skill required	Less time/effort required to learn	More time/effort required to learn
18	Support	Less support required	Dependent on support
19	Experiential learning	Opportunity to learn from personal experience	No opportunity to experiment with
20	Farmer participation	Participatory development of tools	No influence on development
Economic Landscape			
21	Size of farm operation	Bigger economies of scale	Small economies of scale
22	Value of crop	High value crops	Low value crop
23	Available capital	Easily available capital	Capital not easily available
24	Cost savings potential	High potential for savings	Low potential for savings
25	Perceived high risk	Perception of risk is low	Perception of risk is high
26	Current farm technology	Higher level	Low level
Social Landscape			
27	Progressive grower leaders	Many respected leaders	Few leaders
28	Competitive farmer population	More competitive	Less competitive
Physical Landscape			
29	Flexibility of infrastructure	Options available for flexibility	Rigid water ordering in canal bulk water supply schemes
30	Importance of water	High importance	Low importance

Regardless of the large number of studies and suggested theories, low adoption of irrigation scheduling is still widespread. Conclusions and recommendations from the past studies are inconsistent, confusing and varied. Irrigation management is embedded in a complex

agricultural system. There are a multitude of factors which influence behaviour. The literature, however, seems to only list the factors which correlate with adoption behaviour. There is little evidence of attempts to determine the explanatory power of correlations amongst the list of factors. Taking cognisance of the complexity, there appears to be an opportunity to investigate the cause and effect relationships, and the relative strength of factors, in order to identify and understand which are most influential and overriding in irrigation scheduling adoption. In the next section, the theory of complex systems is reviewed in order to gain an understanding of the nature of the adoption problem.

2.4 An Overview of Complex Systems

The above review of literature on the adoption of irrigation scheduling displays the complexity in which the subject matter is embedded. In this section, the adoption of irrigation scheduling is viewed in the context of complex systems. Initially an overview of complex systems is presented, before the characteristics of complex systems and its relevance to irrigation scheduling is introduced. This short section will briefly introduce the difference between simple and complex systems followed by a description of complex system characteristics such as non-linearity, feedback and emergent behaviour. In the last section, irrigation scheduling adoption is qualified as a complex problem.

The world can be viewed as a collection of interlocking systems. Some systems are simple and others complex. Simple systems are those where the behaviour can be clearly defined, modelled and predicted with a high degree of certainty (Pollard *et al.*, 2011). Simple systems can also be complicated. Complicated systems may have numerous parts but are connected in a way to produce a deterministic (predictable) outcome (Pollard *et al.*, 2011). The movement of the planets or aerodynamics of an airplane are examples of complicated but simple systems (Strong, 2013). In these systems, a Newtonian reductionist approach allows for system behaviour to be modelled by accounting for the physical laws which act on individual components (Pollard *et al.*, 2011). These simple, yet complicated, systems are also associated with hard systems. Hard systems are physical in nature and exist in the real world. In hard systems, the components, the system itself and resultant behaviour are typically easier to define, model and optimise in a manner which is acceptable to all (Khisty, 1995).

A complex system on the other hand is described as messy and unpredictable. In a complex system the resultant behaviour is dynamic and difficult to explain or model. It is generally accepted that complexity arises from a large number of interacting and interdependent components or agents (Pannell, 1999). The degree of complexity is attributed to the quantity, quality and resultant behaviour of the web of relationships (Richmond, 1994). The relationships and connectivity between these actors are not always visible or easy to describe. Dominant system drivers can vary over time and space to produce a combination of outcomes that result in uncertainty (Pollard *et al.*, 2011). This is especially true for systems where soft variables interact with hard systems. In a soft system there is uncertainty about what is causing the problem or what a suitable solution would look like (Checkland, 2000). For example, individual world views (mental models) may cause stakeholders to define the problem differently (Khisty, 1995; Stephens and Hess, 1999; Kayaga, 2008). Furthermore, complex systems include time delays and multiple scales.

Simple systems are linear because the characteristics or behaviour of individual components can be used to explain the behaviour of the whole system. For example, Newton's laws of motion allow for the behaviour of the system to be determined by the dynamics of the individual elements prior to, say, a collision. Unlike simple systems, a Newtonian reductionist approach fails to model the behaviour of a complex system. In complex systems the whole is greater than the sum of the parts (Senge, 1990) because individual components cannot be summed up to equate to behaviour of the whole (non-linear) (Stephens and Hess, 1999). Small changes can amplify and have large impacts elsewhere in the system. The size of the cause is not necessarily correlated to the impact it has on the system.

Complex systems are also characterised by the presence of feedback. Circular feedback is when the outcome of an action becomes the cause for the next action, such that the influence propagates through the interconnected system to return and influence the original causal agent, e.g. "decisions cause changes which influence later decisions" (Forrester, 1998). An example of feedback in a simple system is compound interest earned in a bank savings account. Interest earned is a function of the interest rate and the current bank balance. The interest earned in the first time frame, however, alters the current bank balance which in turns alters the interest to be earned in the next time frame (Sterman, 2000). In a complex system, Sterman (2006) suggests that the feedback is less obvious or visible. The point is demonstrated in Figure 2.2. Hence in complex systems, the primary cause of surprising results is a lack of understanding of the

presence of feedback in the system (Sterman, 2006). Policies are often approved and implemented without due consideration of any side effects which may arise from feedback. Consequently, the unintended consequences filters back to alter the state of the system, making the policy ineffective or adding to the cause of the problem. The human brain has been wired to look for the cause of a problem close to the proximity of the problem itself. This failure has led to many management teams missing the critical feedback loops which give rise to the problem.

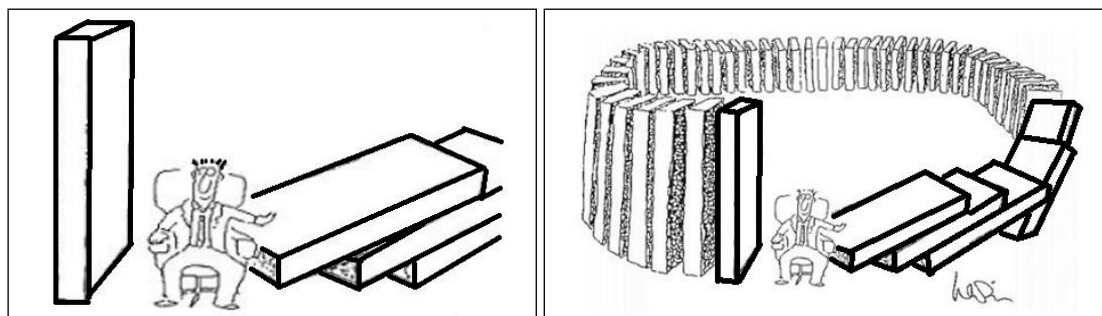


Figure 2.2 Emphasising the need to understand feedback loops (Morecroft, 2008)

In fact, limited understanding of feedback loops (circular causality) has often resulted in the proposed solutions themselves feeding back through the system to give rise, generally over the long term, to some unintended consequence or problem.

Feedback can be better understood by tracking the web of cause and effect relationships in the system (Sterman, 1994). In other words, a deeper understanding of the underlying system structure (the connectivity and interdependency of system components) is required to better understand the cause of behaviour in a complex system. Human incapacity or failure to think systemically and operationally, however, is common. An example is depicted in the illustration in Figure 2.3 below.



Figure 2.3 A lack of systemic thinking (Morecroft, 2008)

By definition, systemic is the word used to describe when a component is innately/inherently a part of the system and any change to the component will invariably propagate some change throughout the system and vice versa. This give rise to the foundational concept that dynamic tendencies/behaviour of a complex system arises from its internal causal structure (Richardson, 2011).

2.4.1 Adoption of irrigation scheduling in the context of complex systems

As stated before, complexity typically arises from the interaction of a large number of hard and soft entities within a system. This is the case for irrigation scheduling adoption. Research and development, technology transfer and on-going support of innovations require the involvement of a number of stakeholders from various disciplines. Table 2.3 lists the wide array of factors cited in literature which influence adoption of irrigation scheduling. Despite efforts to evolve the system and induce change, non-adoption still prevails, indicating some degree of self-organisation or emergence. The dynamic interaction of these factors implies that irrigation scheduling adoption is complex. Both Stevens (2006) and Jakku *et al.* (2007) suggest that agricultural innovation adoption is not a linear process where farmers passively receive knowledge from extension officers. Apart from the multi-disciplinary agents and their respective biases, economic, technical, environmental and institutional constraints together with social and cultural traits, all contribute to the complexity of the system (Jakku *et al.*, 2007).

Pahl-Wostl (2007), Dewulf *et al.* (2007) and Brugnach *et al.* (2008) identified the need to account for complexity in natural resource management. These authors acknowledge that

uncertainty and complexity are unavoidable and called for a movement from prediction and control management style to adaptive management. The methodical hard scientific approach no longer seems adequate. Social learning (Bandura, 1986), soft systems methodology (Checkland and Poulter, 2006), systems thinking (Senge, 1990) and system dynamics modelling (Forrester, 1961), which all aim to deal with complexity, and have been prominent in the management, social and business disciplines (Keating *et al.*, 1999; Sterman, 2000; Morecroft, 2008; Reynolds and Holwell, 2010) have emerged in the environmental-social systems landscape (Pahl-Wostl, 2002; Pahl-Wostl and Hare, 2004; de Chazal *et al.*, 2008; Sterman, 2011). Recognition of the need to account for complexity arising from the interaction of social and environmental systems appears abundant in the realm of water, but only at larger spatial scales such as catchment and policy levels (Stave, 2003; Tidwell *et al.*, 2004; du Toit, 2005; Mostert *et al.*, 2007; Pahl-Wostl and Tabara, 2007b; Pahl-Wostl and Tabara, 2007a; Pahl-Wostl *et al.*, 2008; Pahl-Wostl, 2009; Qin *et al.*, 2010; Goldani and Amadeh, 2011). There is no evidence in the literature of studies which focus on complexities in the form of cause and effect relationships and feedback structures for irrigation management or irrigation scheduling adoption at the farm or field level.

2.5 System Dynamics Modelling

A system dynamics modelling platform provided the researcher with the opportunity to extend beyond simply listing or correlating variables to adoption behaviour, as was the case in the irrigation literature. In this section, a brief introduction to system dynamics is offered followed by the rationale for using the system dynamics platform. In addition, literature from the system dynamics modelling fraternity is also cited to demonstrate the historic use of the modelling platform in the context of adoption and diffusion of a wide spectrum of innovations, but not for irrigation scheduling.

2.5.1 Rationale for using system dynamics modelling and novelty of the project

System dynamics modelling is a technique for framing, describing, understanding and communicating complex problems or processes (Forrester, 1991). Mathematical equations are used to simulate the interactions and feedbacks between system components, which often uncover non-linear behaviour (Forrester, 1998). System dynamics shows how variables change through time (Forrester, 1991).

System dynamics modelling relies heavily on the accurate depiction of system structure. Stock and flow or causal loop diagrams (Lane, 2000) are used to demonstrate how behaviour and feedback arises systemically from a web of circular cause and effect relationships embedded in a system. In other words, emphasis is placed on capturing the internal forces which result from either the context or decision rules/policies that drive action (Richardson, 2011). The uncovering of system structure and placement of system boundaries through the process of constructing a systems dynamic model, with stakeholder participation, helps to improve understanding of the complexity of the operating environment. The process also strengthens the relationship with stakeholders by ensuring that the respective realities are understood and appreciated. These appear to directly address the issues raised by Stevens (2006), Vanclay (2004), Jakku *et al.* (2007) and others like Pahl-Wostl (2007), who called for better communication and more interaction amongst scientists, extension and farmers.

Fisher *et al.* (2000), based on a review of literature, concluded that system dynamics was better than previous mathematical models because of the transparent illustration of feedback, which is conducive for learning, and learning is necessary for technology adoption. Many examples can be found in the literature where system dynamics modelling was used to better understand the innovation diffusion process and/or guide future policy or actions to improve adoption rates. Case studies include, amongst others, epidemiology and contagion effects in the medical sciences (Dangerfield *et al.*, 2001; Homer *et al.*, 2004; Galea *et al.*, 2010; Paich *et al.*, 2011), corporate product development and diffusion (Milling, 1996; Maier, 1998; Milling, 2002; Ripenning, 2002; Oliva *et al.*, 2003; Weil, 2007; Barran, 2010), the information technology industry (Pardue *et al.*, 1999) and sustainable environmental/agriculture systems (Arquitt *et al.*, 2005; Halog and Chan, 2008; Harich, 2010).

Fisher *et al.* (2000) used system dynamics modelling in the context of adoption and diffusion of yield monitoring and mapping technologies for precision agriculture. Similarly, Kopainsky and Derwisch (2009) used system dynamics to explore strategies for fostering adoption of improved seed in West Africa. Davis and Durbach (2010) used a system dynamics approach to explore the household response to energy interventions in South Africa. Grobelaar (2006) also made use of system dynamics modelling to study the sustainability of South Africa's ability to generate research and development outputs. Only a handful of system dynamics modelling applications in South Africa can be found in the literature (Kaggwa *et al.*, 2006; Mussango *et al.*, 2009), none of which involved agricultural systems, water or technology adoption. The lack

of dedicated literature suggests that, worldwide, nobody has used System Dynamics modelling to study the adoption of irrigation scheduling.

This concludes the literature review chapter. In the next chapter, the materials and methods used in this study are presented. This includes an introduction to the case study area and the organisational context of the funding institute, for who this research study was commissioned. The process for building system dynamics models and associated processes for eliciting data are also discussed.

3. MATERIALS AND METHODS

The research paradigm used in this work aligned with grounded theory, where in a pre-hypothesis phase, data is iteratively obtained in order to propose an underlying theory. In this case, the formulated theories, to explain the adoption process of irrigation scheduling in the case study area, were captured and communicated via system dynamics models. This chapter presents the formal process for construction of a system dynamics model, and the techniques used to elicit data in order to shape and structure the system dynamics model. The organisational context and case study area is first introduced in Section 3.1.

3.1 The Research Context

This study was funded by and conducted for the South African Sugarcane Research Institute (SASRI). SASRI has a rich history of research excellence and has contributed substantially to the body of scientific knowledge for the production of sugarcane. SASRI's research spans across a spectrum of disciplines such as plant breeding, pest and diseases, soil health, weeds, biotechnology, agronomy and agricultural engineering (SASRI, 2015). SASRI is funded by the sugar industry (millers and farmers) via a research levy. Agents responsible for transferring technology to farmers include the Knowledge Management Unit (KMU) at SASRI and the various Extension Specialists, who each serve a specific geographic region. SASRI's research outcomes and recommendations are made accessible to the farmers via printed media, formal courses, grower days, field demonstrations, an annual sugar conference, customised problem solving by scientists and one-on-one extension. Despite the effort and resources directed towards technology transfer activities, adoption and uptake have still been well below expectation in the irrigation sector (Reinders, 2001; Olivier and Singels, 2004 and Singels; 2007). As will be shown later in Section 5.1 (Figure 5.2), adoption in the case study area, Pongola, was particularly low.

Figure 3.1 depicts the geographic layout of the South African sugar industry. The case study area, Pongola is situated in the irrigated north, \pm 360 km away from SASRI's head office. Pongola is dominated by agriculture with approximately 21 500 ha under sugarcane production. Less than 500 ha is cultivated with fruit trees such as citrus and mangoes and some vegetables are grown on sugarcane fields as a rotation crop. Virtually all sugarcane produced in the region

is supplied to the mill in Pongola for the production of sugar. The sugar mill and associated agricultural development was established in the early 1950s. Due to the low rainfall and high temperatures, sugarcane production is not possible without irrigation in Pongola. Farmers are totally dependent on the natural water resource, which is predominantly sourced from the Pongola River. The construction of the Bivane dam in the year 2000 stabilised the supply of water to irrigators to a large degree, despite erratic rainfall seasons. Over-head sprinkler systems were the dominant irrigation method. Water is abstracted both from an extensive canal bulk water supply scheme and directly from the river, depending on geographic location and the timing of farm establishment.

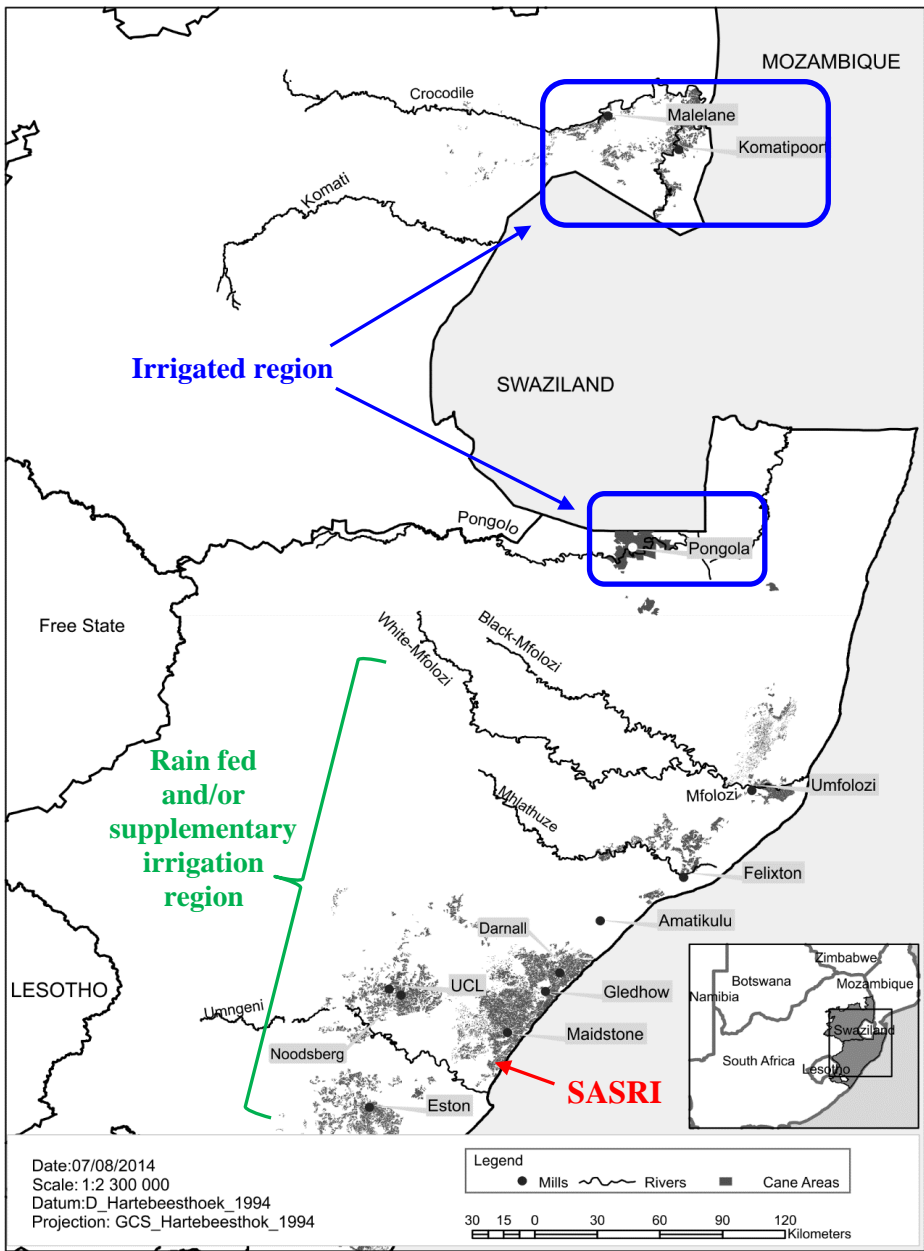


Figure 3.1 Depicting SA sugarcane industry and the case study area

In contrast to the rest of South Africa, the Pongola catchment was not considered a water stressed catchment (Anon, 2014). The Bivane Dam and relatively good management by the local water users’ association, Impala, ensure that water has been readily available for irrigators within the authorised schedule of allocations. Unfortunately, when water is readily available, the value of water diminishes in the minds of farmers. As a result, the tendency for over irrigation prevailed in the case study area. Reinders *et al.* (2016) documented the history of rising water tables and the dramatic need for subsurface drainage in large areas of irrigated sugarcane in the case study area. Adendorff (2015) also reported that the historic crop yields were, on average, 40% lower than the climatic potential. To some extent, the poor yields were attributed to poor irrigation management practices. In exploratory interviews in the case study area, a number of farmers agreed that over-irrigation was a problem, revealing that many farmers would look to borrow water from their neighbours, having already used up their allocation for the season.

Extension services in the Pongola area have been inconsistent. As shown in Table 3.1, between 1993 – present, there were two separate periods (a three-year period and a five-year period) during which farmers in Pongola chose to not subscribe to the SASRI extension service. This decision was largely an economic decision. Farmers felt that extension services were too expensive (Adendorff, 2014). The absence of extension provided fertile ground for misinformation and a dramatic decline in management practices and subsequent sugarcane yield (Adendorff, 2015).

Table 3.1 Tabulating the presence of extension services in Pongola

		Years	Duration
1	No extension	1991 – 1993	3 years
2	Individual 1	1994 – 2000	
3	Individual 2	2001 – 2004	
4	No extension	2005 – 2009	5 years
5	Individual 3	2010 – current date	

In the next section, a summary of the process used for constructing the system dynamics models in this research study is presented. In addition, the relevant system dynamics modelling literature supporting the construction process is also cited.

3.2 System Dynamics Model Construction Process

The STELLA[®] software (ISeeSystems, 2015), available from www.iseesystems.com, was used for mapping, coding and simulation of the system dynamics models in this study. STELLA is an acronym for “Structural Thinking, Experiential Learning Laboratory with Animation” (Richmond, 1985). The process of constructing a system dynamics model is not cast in stone, but fairly well designed. Table 3.2 summarises the various recommendations from the classic literature of system dynamics modelling. While there are subtle differences in the titles for each modelling phase amongst the past authors, the essence of model construction is similar.

Table 3.2 The system dynamics modelling process across the classic literature, after Luna-Reyes and Andersen (2003)

Randers (1980)	Richardson and Pugh (1981)	Roberts <i>et al.</i> (1983)	Wolstenholme (1990)	Sterman (2000)	
Conceptualisation	Problem definition	Problem definition	Diagram construction and analysis	Problem articulation	
	System conceptualisation	System conceptualisation		Dynamic hypothesis	
Formulation	Model formulation	Model representation	Simulation phase (stage 1)	Formulation	
Testing	Analysis of Model behaviour	Model behaviour		Simulation phase (stage 2)	Testing
	Model evaluation	Model evaluation			
Implementation	Policy analysis	Policy analysis and model use	Simulation phase (stage 2)	Policy formulation and evaluation	
	Model use				

In the first phase of model construction, the problem is defined and elements which act together to create the root cause of the problem are conceptualised. This typically involves a mapping

of system components and the dynamic way in which they interact. The result is usually a descriptive model. In this study, the conceptualisation phase involved synthesising literature and eliciting data from actors in the system to map the causal relationships and structure. Conceptualisation proved to be the largest and most difficult component of the project. More details of the process will be shared in Section 3.3. The initial results are shared in Chapter 4.

In the system dynamics model construction process, after the conceptualisation phase, the descriptive model is transformed into a simulation model. The model formulation requires the mathematical representation of the causal relationships in the system. Care is taken to accurately and precisely represent the various laws, policies, decision rules, assumptions and beliefs which typically govern the relationship and hold in place the structure between the components of the system.

The next phase involves testing the model. Model testing in system dynamics is not the same as model validation in the physical science disciplines. In the physical sciences, a model is validated when simulated results are comparative to observed results for a wide range of input conditions (El Sawah and Mclucas, 2008). By definition, complex systems are unpredictable and messy. Very rarely is data from the real world available for the full range of plausible conditions. Hence validation through repeated comparison of model results and observed reality is usually not possible (El Sawah and Mclucas, 2008). In the system dynamics fraternity, model testing relates to building confidence in the model. Various tests such as a dimensional consistency, extreme condition and boundary adequacy tests are prescribed to ensure that the model can be used with confidence (Shreckengost, 1985).

The sequence of conceptualisation, data collection, model formulation and testing is flexible and not necessarily chronological. An iterative process encourages deeper learning about the system structure and the resultant modes of behaviour (Sterman, 2000). The iterative and fluid nature of model construction, as recommended by the experts, allows for the feedback process to inform ongoing questioning, testing and refinement of both the virtual and mental models (Sterman, 1994). This concept is depicted in Figure 3.2. The reader should make a special note that a major outcome of a system dynamics modelling project, such as this one, is not merely the finished model product itself. Potentially, the more important outcome is the revised mental models, and/or revised behaviour, of stakeholders who engaged in the process of model conceptualisation, formulation and testing.

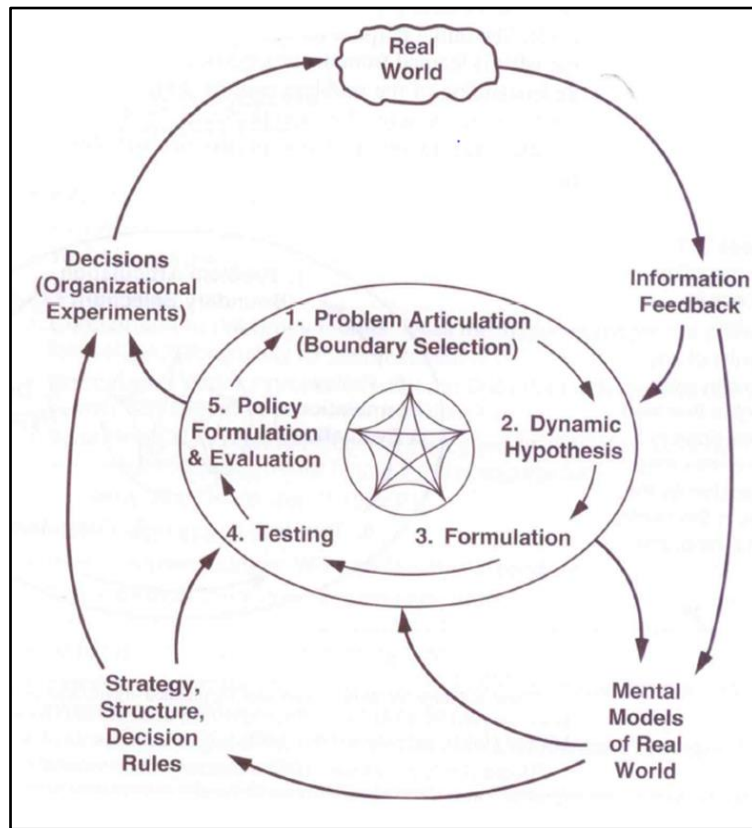


Figure 3.2 A depiction of iterative model construction stimulating experimental learning in both the virtual and real world, after Sterman (2000)

Figure 3.2 also alludes to the final phase of the model construction process. A refined model based on sound logic, accurately capturing the underlying structure of the system and capable of regenerating the problematic behaviour, can be used in the final phase to conceptualise and test policies or interventions to correct the problem situation. In the absence of system dynamics models, proposed solutions, policies or interventions are implemented, typically based on intuition. Leaders have no tools to assess the impact of any proposed solution prior to implementation. The system dynamics simulation model provides a safe virtual environment for thinking through and exploring the systemic impacts (feedback) of any intervention prior to implementation. This is especially powerful when a participatory approach is adopted and a range of stakeholders (with their unique knowledge) are invited to view and contribute to the development and testing of solutions.

This concludes the overview of the construction process of a system dynamics model. In the next section, the research paradigm and methodologies for data elicitation is presented. In this

study, data was, firstly, required to map and conceptualise the structure of the complex system of adoption of irrigation scheduling. Secondly, engagement with the real world was necessary for testing both the plausibility of simulation scenarios built and the corresponding results simulated by the model.

3.3 Theoretical Framework for Data Elicitation and Subsequent Methodologies

A comprehensive review of techniques and models for collecting and analysing qualitative data for system dynamics methods is provided by Luna-Reyes and Anderson (2003). Luna-Reyes and Anderson (2003), citing Forrester (1962), emphasised the importance and central role of qualitative data in the construction of a systems dynamics model. Forrester (1991) states: “Human affairs are conducted primarily from the mental data base. Anyone who doubts the dominance of remembered information should imagine what would happen to an industrial society if it were deprived of all knowledge in people’s heads and if action could be guided only by written policies and numerical information. There is no written description adequate for building an automobile, or managing a family, or governing a country. People absorb operating information from apprenticeship and experience”. Figure 3.3 was later used to annotate the above idea (Forrester, 1992).

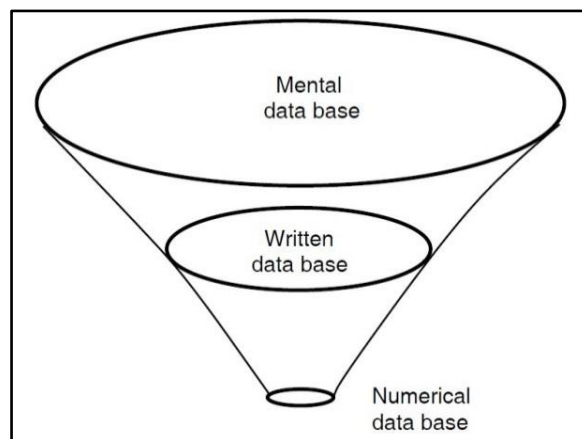


Figure 3.3 Decreasing information content in moving from mental to written to numerical data bases (Forrester, 1992)

In addition, Senge *et al.* (2008) reaffirmed the argument that mental models and belief systems are most influential in shaping the structure and resultant behaviour of a complex system. This idea is explained using an iceberg analogy, depicted in Figure 3.4. In the bio-physical reality,

the non-visible component of the iceberg structure (occurring below the water surface) is not only larger, but is also the portion on which the ocean currents act, subsequently shaping the behaviour (movement) of the visible component (above the water surface).

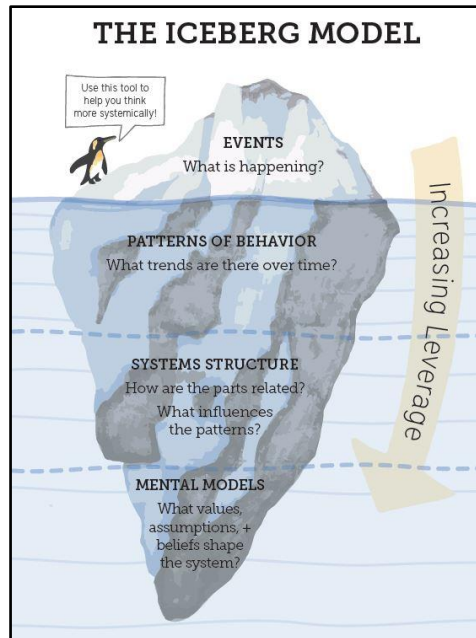


Figure 3.4 Iceberg analogy to depict the strength and subsequent leverage of mental databases (Meadows, 2015, after Senge *et al.*, 2008)

Similarly, non-visible components such as mental models comprising of beliefs, value systems, underlying assumptions and their interactions condition the visible behaviour modes of social systems. Forrester (1991), Forrester (1992), Ford and Sterman (1998), Luna-Reyes and Anderson (2003) and Senge *et al.* (2008) conclusively establish the importance of penetrating deeply to access the mental models when eliciting data from stakeholders in order to discover and map the causal structure of a complex system.

Luna-Reyes and Anderson (2003) systematically reviewed and commented on the suitability and acceptability of using various social science techniques and models in the different phases of constructing a system dynamics model. The data collection techniques that supported system dynamics modelling, historically, included structured and unstructured interviews, oral history, focus groups, Delphi groups, observation, participant observation and experimental approaches. Similarly, models used for qualitative data analysis by system dynamics modellers included hermeneutics, discourse analysis, ethnographic decision models, content analysis and grounded theory.

3.3.1 Grounded theory

Grounded theory is specifically highlighted to the reader in this section. Over and above spelling out the methodological paradigm, the intention is to also equip the reader with the appropriate theoretical framework for viewing the results. In this regard, grounded theory principles formed the basis for this research. Grounded theory refers to the discovery or generation of theory from data systematically obtained from social research (Glaser and Strauss, 1967). Grounded theory operates in a reverse fashion and may appear to contradict scientific method (Choles *et al.*, 2014). Traditionally, researchers formulate a hypothesis upfront. Methods are then devised and data gathered, to either prove or disprove the hypothesis. Grounded theory, however, operates in a reverse fashion (Choles *et al.*, 2014). The first step is data collection, which in system dynamics terms refers to mapping the complex system or conceptualising the causal structure. This is usually achieved by engaging with actors in the system to elicit data. Analysis of the initial data then informs many further iterations of data collection and analysis throughout the research process until core conceptual ideas emerge to form a theory (Corbin and Strauss, 2015). In this study, Grounded theory provided a flexible paradigm in which a wide net could be cast to capture contextual richness and depth of understanding of the causal factors, which aligned well with the systems thinking paradigm of stepping back to see the larger system (the 10 000 m rule of Richmond (2005)).

Narrative enquiry (after Choles *et al.* (2014) and Kurts (2014)), via exploratory interviews with farmers, was a key method to elicit data at the farm level. In addition, evidence from literature and observation of scientists, colleagues in knowledge management and extension specialists also served as a pathway for obtaining data at the scientist's level, where innovations are designed and packaged, and at the level of knowledge management and extension, where knowledge is shared and technology supported. The data from exploratory interviews, literature and observation was not collected sequentially. The data was collected in parallel, iteratively and, sometimes in very informal settings, over a period of 4 years. As will be demonstrated in the results chapters, the data was used to formulate or reverse engineer theories which explain adoption behaviour in a complex agricultural system. The system dynamics models were, therefore, a means for capturing, describing, formulating, testing and communicating the causal and behavioural theory of the complex system (Forrester, 1991). A basic description of the individual pathways for data collection is presented below.

3.3.2 Drawing from literature

Literature was scanned in order to identify and map the key variables, their interdependence and their interaction in shaping behaviour in adoption decision making. Aspects of this component have already been presented in Chapter 2. For example, Table 2.2 presents, illustratively, the frequency with which recurring themes appeared in the literature. A more detailed inventory of the actual factors cited in the irrigation literature was also presented in Table 2.3. During the construction and testing of the system dynamics models, it was necessary to consult with literature beyond the irrigation discipline in order to justify and/or gain confidence in the plausibility of model structures and feedback loops. This will become more evident in the result chapter (Section 4.1), where additional literature is cited to anchor and justify certain model components and feedback loops.

3.3.3 Semi-structured exploratory interviews to obtain narrative data

The data extraction process via semi-structured interviews is well established in the scientific community. It has been applied in System Dynamics Modelling (Forrester, 1992; Luna-Reyes and Andersen, 2003), Participative Narrative Inquiry (Kurts, 2014) and Soft Systems Methodology (Checkland and Poulter, 2006). The semi-structured interview methodology, within the framework of Soft Systems Methodology, was also recently applied in the South African sugar industry to study social complexity in a supply chain environment (Gerwel Proaches and Bodhanya, 2013; Gerwel Proaches and Bodhanya, 2014; Gerwel Proaches and Bodhanya, 2015). A semi-structured explorative interview process was used to engage with a selection of ten farmers in the case study area. Aligned with the principles of grounded theory, the objective was to elicit data without any preconceptions or predetermined hypothesis. Therefore, no structured questionnaire was used. Instead, a framework of key focal areas was used to stimulate conversation or discussion with growers for the explicit purpose of extracting narratives which reflect the assumptions, belief systems and values which shape the existing decision making and behavioural system.

The grower sample selection was informed by the local extension specialist and sugarcane supply officer. The grower sample represented the range of adopter categories, including non-adopters, slow and faster adopters. The extension specialists selected growers in the various

adopter categories based on the farmers' historical behaviour tendencies with other agricultural innovations. Depending on the extension specialist and sugarcane supply officer to select the sample of growers for the interview was considered acceptable, since these individuals know the farmers intimately. Working in the capacity of advisory services over a number of years allows the extension specialist and sugarcane supply officer to learn about both the farms (in terms of yield potential, scale of operation, financial situation and production levels) and the farmers (in terms of skill, education, social tendencies and personality traits). All interviews were audio recorded and transcribed. The key focal areas, typical questions and the aim for asking such questions are briefly summarised in Table 3.3.

Table 3.3 Summary of the flexible structure used for exploratory interviews with farmers

Focal Area	Sample of Typical Questions Asked	Aim
Farm/Yield performance	<ol style="list-style-type: none"> 1. What is the current average yield on the farm? 2. Has the average yield changed historically? 3. Reasons for change? 4. Is there a goal to improve yield? How do you explain the difference between current yields and the yield goal? What strategy is being used to improve yields? 	<ol style="list-style-type: none"> 1. To benchmark the current farm performance. 2. To get clues w.r.t the farmers' comfort zones, attitude and enthusiasm for farming. 3. To discover the belief system about current performance levels and room for improvement.
Choice of irrigation systems	<ol style="list-style-type: none"> 1. What irrigation systems do you have on the farm? 2. How did you select which systems to use? 3. Are you considering any changes? How do you make the decision? 	<ol style="list-style-type: none"> 1. To get a preliminary sense of habitual thinking patterns w.r.t on-farm decision making.
Irrigation scheduling	<ol style="list-style-type: none"> 1. How do you decide when to irrigate and when to switch off? 2. If you don't schedule: <ol style="list-style-type: none"> a. Why not? 3. If you do schedule: <ol style="list-style-type: none"> a. How did you learn about the scheduling tool? b. What was the reason for adopting? c. Was it an easy decision? Did it take a long time to make the decision? d. Did you trust the tool right from the start? 	<ol style="list-style-type: none"> 1. To benchmark the status quo w.r.t irrigation scheduling. 2. To ascertain reasons for adoption or non-adoption 3. To identify or confirm the decision making pattern. 4. To ascertain if the decision was easy for the farmer. 5. To learn how farmers become aware of a new technology.

Table 3.3 Continued...

Focal Area	Sample of Typical Questions Asked	Aim
Farm history, education and learning	<ol style="list-style-type: none"> 1. How long have you been on the farm? 2. How did you learn to farm? 3. Did you obtain a qualification? 4. What would you recommend for new farmers? 5. How do you learn about new farming technologies? 6. Do you make use of the extension specialist? When and how? 	<ol style="list-style-type: none"> 1. Firstly, to dissipate any discomfort a farmer may have felt in answering the questions in the previous focus area. 2. To test if the thinking pattern for decision making about new innovations, outside of irrigation, was still the same.
Ranking of farm input costs	<ol style="list-style-type: none"> 1. What are the big cost components in farming? 2. How does this affect managing the farm? 	<ol style="list-style-type: none"> 1. To detect the strength of cost as a motivating factor for better management in any specific area.
Water Availability	<ol style="list-style-type: none"> 1. What is the water situation like? 2. Do you have enough water? Is it a concern? 3. How do you access the water? 4. Do you monitor or record your water use? 5. Is water cheap or expensive? 6. How are the water bills calculated? 	<ol style="list-style-type: none"> 1. To detect the mind-set/paradigm w.r.t water (as a scarce resource) and irrigation management in the farmers' mind.
Performance as a community	<ol style="list-style-type: none"> 1. How would you score the way the farming community uses water as a whole? Are the guys efficient and getting things right? 	<ol style="list-style-type: none"> 1. To confirm or reaffirm the mind-set/paradigm w.r.t water (as a scarce resource) and irrigation management.

A similar exploratory process was used to conduct semi-structured interviews with two extension specialists. The first interview was with a SASRI extension specialists who served an area different from the chosen case study area. The second interview was with the retired extension specialist who worked in the case study area during the 1994 – 1999 period. The main aim of these interviews were to gain insight on belief systems about farmers, methodologies for encouraging adoption of any BMP and flaws or weaknesses in SASRI's organisational culture with respect to adoption. The interviews with the two extension specialists, in comparison to the farmer interviews, were far more exploratory and less structured. A summary of the typical questions asked is presented in Table 3.4.

Table 3.4 Typical questions posed to extension specialists in the exploratory interviews

Focal Area	Sample of Typical Questions Asked	Aim
Extension perceptions of farmers and Extension methods	<ol style="list-style-type: none"> 1. Is there a pattern or typology in a community for adoption of BMPs? For example, does the grower leadership adopt first? Or do individuals have specific preferences where they adopt some BMPs and not others? 2. Do you spend more time and give more attention to growers who are known to be adopters and less on the non-adopters? 3. Is it true that the good growers always attend grower days and those who need the information do not attend? 4. How would you communicate to a farmer that he was doing something wrong and you wanted him to change it? 5. If a farmer invites you on to the farm to look at a problem, but while you are there you discover a more serious problem, how would you deal with that? 6. I have heard many extension specialists say, “Never <u>tell</u> a farmer what to do. Wait for them to ask”. Is that correct? 7. How do you deal with a situation where you provided advice and the farmer has not implemented anything? 	<ol style="list-style-type: none"> 1. To surface belief systems and perceptions which direct or dictate extension approaches. 2. To surface the default or preferred extension methods. 3. To benchmark what techniques or tactics are believed to be most effective.
SASRI practices	<ol style="list-style-type: none"> 1. How do farmers perceive SASRI’s written media (e.g. the LINK)? 2. What is your strategy with extension newsletters? 3. Are SASRI grower days effective? How can we improve it? 4. Explain how and when you use the study circle concept? 	<ol style="list-style-type: none"> 1. To explore possible flaws and/or weaknesses in current communication and knowledge sharing pathways. 2. To discover which communication options are preferred in which contexts.

The transcribed narrative data was not analysed using any specific software. The author read through the transcriptions several times, and flagged recurring themes and ideas which aligned with the causal factors or themes identified in the literature. Specific sentences or paragraphs, which best captured the underlying beliefs, assumptions and or causal forces were extracted from the transcribed data. The results of this work are reported in Section 4.2.

3.3.4 Observation

The target audience for this study were the agents responsible for encouraging and supporting adoption. At SASRI, this comprised of the knowledge management unit and extension, and to a lesser extent, researchers. It was therefore, opportune for the author, as an employee of SASRI, to continually observe narratives and underlying mental models, in various conferences, workshops, meetings and informal conversations (at the tea station, on farm visits and around dinner braai fires). In addition, the author was also able to observe the reactions and responses, and obtain feedback when the target audience was exposed to the various versions of the system dynamics models or other content from the project. As already illustrated in Figure 3.1, model building is an iterative process, which allows for continuous and systemic learning and renewal of mental models amongst the participants. Relatively frequent sharing of model development with the extension specialist in the case study area largely negated the need for a follow up session with farmers. The extension specialists, by reflecting on their experiences and understanding of the real world against the models, either provided confirmation that the model was well attuned, or suggested corrections for the model. The development of the negative word of mouth model fragment, presented in Chapter 5.2, is an example of how feedback narratives influenced an expansion in the model structure. This completes the Methodology Chapter. The Results Chapter is presented next.

4. RESULTS (PART 1): EVIDENCE FROM LITERATURE AND NARRATIVE DATA

The results of the study are presented in the Chapters 4, 5 and 6. The first set of results, presented in this chapter, include evidence extracted from literature and narrative data collected from farmers and extension specialists during the course of the study. The evidence from literature and narrative data was used to conceptualise the system dynamics models. Two main themes emerged from the literature and narrative data. The first is the concept of peer interaction, i.e. word of mouth. The second theme relates to the idea of on-farm testing of an innovation. These two causal themes became the subject for exploration in two different system dynamics models, presented in the Chapter 5 and 6.

4.1 Important Extracts from Literature

It is unusual for literature to be presented in the results section. The main aim of this project, however, was to map the causal relationships of key variables in the adoption of irrigation scheduling innovations. In the literature review component of this thesis, literature was presented from within the irrigation fraternity. The main aim in the literature review section earlier in the thesis was to confirm the gap in knowledge and that past efforts have not yet adequately resolved the problem of poor adoption of objective irrigation scheduling. In this section, information is drawn from literature bodies outside of the irrigation fraternity. The material presented in this section was especially instrumental in conceptualising and shaping the system dynamics model, which in turn was developed in order to explore ways to fill the knowledge gap. The literature extracts presented in this section is therefore considered as important data or evidence which was used to conceptualise and support the various causal relationships mapped out in the subsequent system dynamics models. The main findings in this chapter directly address the second objective of this project, which was to identify and map the key factors influencing adoption.

4.1.1 Classical diffusion of innovation theory

Emerging from the discipline of rural sociology, the diffusion of hybrid corn seed amongst farmers in the state of Iowa, USA, (Ryan and Gross, 1943) was reported to be the most

pioneering and influential study on the diffusion of innovations (Rogers, 1962). Subsequently, the 5th edition of the classical innovation diffusion theory (Rogers, 2003), continues to report the original framework for diffusion with some refinement arising from the thousands of ensuing studies on diffusion. In the 5th edition, Rogers (2003) described diffusion as “the process through which an innovation spreads via communication channels over time among members of a social system”. The theory elaborates on the 4 distinct elements of innovation diffusion. The 4 elements include the characteristics of the innovation itself, communication channels, the social system and the time frames for adoption.

The characteristics traits of an innovation influence the perception and attitude of the end user which in turn influences the rate of adoption. An innovation can be attributed with characteristics such as the conferring of a relative advantage, ease of testing on a smaller scale, compatibility and observability of results, all of which are influential on the adoption decision (Rogers, 2003). For example, if an innovation offers a higher relative advantage, the likelihood of faster uptake is stronger.

Rogers (2003) explains that adoption is a process played out over time. It is not an instantaneous phenomenon. Time refers to the time taken for an individual to move through the decision making stages, depicted in Figure 4.1. An individual is said to move through the following stages:

- a) Knowledge - knowledge on the innovation is first received
- b) Persuasion - relating to the individual forming an attitude towards an innovation
- c) Decision - to adopt or reject
- d) Implementation
- e) Confirmation - continued adoption or dis-adoption

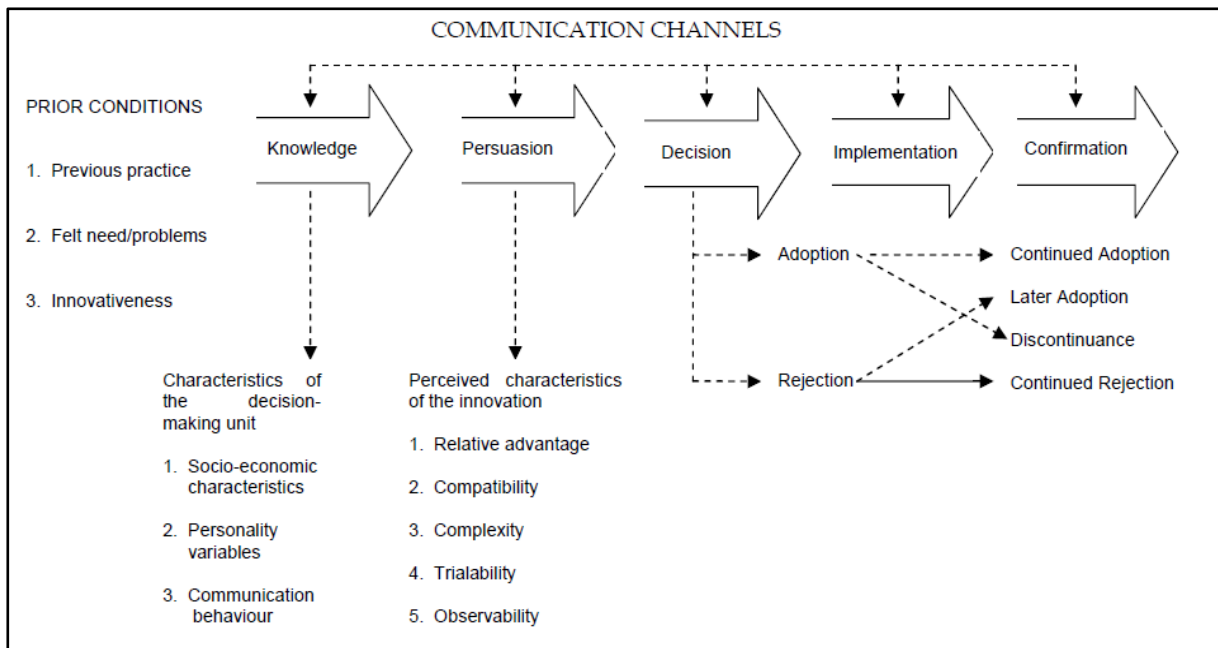


Figure 4.1 Illustration of the process and key influences in classical diffusion of innovation theory (Stevens, 2006, following Rogers, 2003)

The third and fourth components of the classical theory of innovation diffusion were communication and the social system.

“Communication is coupled to the social system component of innovation diffusion theory. Communication and persuasive capabilities are greater between individuals of similar socio-economic (and/or education) status. Most studies illustrate that individuals do not evaluate an innovation based on objective scientific studies. Instead, information from subjective evaluations is sought from other individuals similar to themselves, who may have already adopted the innovation” (Rogers, 2003).

This interpersonal communication is often referred to as word of mouth.

Rogers (2003) categorised the population according to their innate characteristics and relative speed in deciding to adopt. This is summarised in Figure 4.2 below. The adopter categories, ranked according to speed of adoption were: innovators, early adopters, early majority, late majority and the laggards. The second group, the early adopters, are respected by non-adopters and often recognised as the opinion leaders. Non-adopters often look to this group for advice and information about new ideas. The early adopters therefore have the most influence in persuading peers.

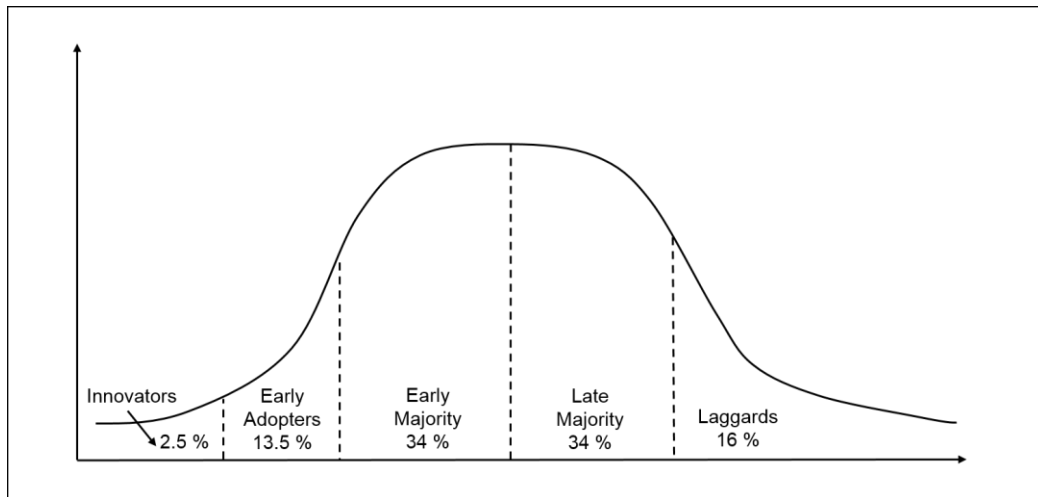


Figure 4.2 Adopter categories according to speed of adoption (following Rogers, 2003)

Resonating with the classical innovation diffusion theory, a foundational mathematical model, the ‘Bass Diffusion Model’, was introduced to estimate new product growth amongst consumers (Bass, 1969). The Bass model assumed that the first group to adopt, namely, the innovators, depended mostly on mass media as a communication channel to induce adoption, while the remainder of the population were categorised as ‘imitators’ (Mahajan *et al.*, 1990). Mass media was considered ineffective amongst the imitator group. The remaining majority of the population depended strongly on word of mouth from peers who experienced the product.

Interestingly, the idea of peers contacting each other, gave rise to the use of the so called epidemics model (depicting the sudden and rapid spread of contagious diseases) in diffusion studies (Geroski, 2000). Researchers began to draw parallels between the sudden break out of a disease and how it spread (diffused) among a population of infected and uninfected individuals, and that of fashion trends, fads and social behaviour patterns (Gladwell, 2000). “*Ideas, products, messages and behaviours spread like viruses do*” (Gladwell, 2000). These studies branded the word of mouth influence collectively as social contagion, i.e. contagious behaviour. Both the epidemics- and bass-diffusion model, also formed the basis for a number of system dynamics modelling exercises in the context of diffusion and word of mouth (Sterman, 2000).

The narrative data presented in Section 4.2, will independently confirm the strength and presence of word of mouth in the case study area, warranting further exploration via the construction of a system dynamics model. The system dynamics model will be presented later in Chapter 5.

4.1.2 On-farm testing as a process for inducing adoption

Amir *et al.* (1999), Pannell (1999), Marra *et al.* (2003) and Pannell *et al.* (2006) present a series of ideas regarding the adoption process and influential causal themes. Different from the diffusion of innovation theory, the information presented below largely relates to the inner thought processes an individual farmer may go through when considering an innovation for adoption. Pannell *et al.* (2006) asserted that “adoption is based on subjective perceptions or expectations rather than on objective truth”. Beliefs and assumptions can override facts when influencing behaviour. This idea resonates with the iceberg analogy presented in Figure 3.3, in Section 3.2, and further supports the value of the narrative data which provides a window to surface and view beliefs, assumptions and decision rules.

Amir *et al.* (1999) reported that adoption decisions were dynamic in nature. Changes in farmers’ perception and attitude occur as information is progressively collected. Amir *et al.* (1999) presented a framework where adoption was conceptualised as a multi stage decision process involving “*information acquisition*” and “*learning by doing*”. Pannell *et al.* (2006) went on to further state that the process of individual learning and experience is influential on the adoption process. “*Early in the process, the farmers’ uncertainty about an innovation is high*” (Pannell *et al.*, 2006). Pannell (1999) presented the following narrative about farmers’ initial approach to a new farming system:

“They are likely to come to it with scepticism, uncertainty, ignorance, prejudices and preconceptions and with an existing farming system that may or may not be operating as they would wish, but is at least operating. Unless they are new to farming, they will have trialed other innovations in the past and concluded that at least some of them fell far short of the claims made for them. They will be particularly wary of a system that is radically different from that with which they are familiar and comfortable. They will almost certainly hold an attitude that the scientists advocating such a radical system do not understand the realities of farming, or at least of their farm”.

In an attempt to reduce the uncertainty, a farmer will begin to note, collect, integrate and evaluate information about the innovation. A farmer will also seek to learn from what others experienced with the innovation, and to some extent, even delay their own decision making

until such information becomes available. The following excerpt was taken from Marra *et al.* (2003):

“There is an option value of waiting to invest when there is uncertainty about the future payoffs and sunk costs in the sense that one cannot recoup all investment costs when disinvesting (also called the degree of irreversibility of the investment). The option value of waiting to adopt is related to the opportunity to observe earlier adopters’ experience with the technology”.

Overcoming the sense of uncertainty and risk by collecting information from a multitude of sources appears to be a key process in the initial phases. This process is dynamic and occurs over a period of time (Amir *et al.*, 1999). To a large extent this process informs the decision of whether or not to go to the next step of trialing the innovation (Pannell *et al.*, 2006). Pannell *et al.* (2006) further suggested that:

For a farmer “to be willing to trial an innovation, the farmer’s perceptions of it must be sufficiently positive to believe that there is a reasonable chance of adopting it in the long run”.

Pannell *et al.* (2006) emphasised that innovations are more likely to be adopted when innovations have a high relative advantage and when they are readily triable. The relative advantage was related to the “*perceived superiority to the idea or practice that the innovation supersedes*”. The relative advantage, relating to the perceived economic benefit and attractiveness of the innovation, is also well documented as a dominant and influential characteristic trait in the adoption process (Sunding and Zilberman, 2001). Any innovation with low or no relative advantage appears to be a non-starter.

If the criteria of relative advantage is adequately illuminated by collection of information, a farmer will likely move on to a second stage, small scale on-farm testing. The extract below provides an insight about the benefits and importance of on-farm testing, with respect to reducing perception of uncertainty.

“There is strong evidence that, the world over, most farmers are ‘risk-averse’ (Antle, 1987; Bardsley and Harris, 1987; Binswanger, 1980; Bond and Wonder, 1980; Myers, 1989;

Pluske and Fraser, 1996). This is evident from the observation that they will not leap into large-scale adoption of a new innovation. Rather, they generally employ small-scale trials, adjusting the scale either upwards towards full adoption or downwards towards disadoption as they gain knowledge and confidence in their perceptions about its performance. This trial phase is very important, perhaps the most important phase in determining final adoption or disadoption” (Pannell, 1999).

Over and above reducing the perception of risk, experience from on-farm testing also creates the opportunity for the farmer to develop the necessary skills associated with the innovation. This was phrased as “*learning by doing*” (Amir *et al.*, 1999 and Pannell *et al.*, 2006). The distinct, but subtle, difference between knowledge of an innovation and experience with an innovation appears to be the difference maker in bringing about faster and successful adoption.

In the South African sugarcane industry the use of strip trials, demonstration plots and model farms to allow farmers to get personal experiences with an innovation was ranked highly to stimulate adoption in 3 different scientific disciplines. van Heerden *et al.* (2014), demonstrated an increased application of chemical ripeners per unit area of 47 % over 3 years as a result of strip trials in conjunction with grower days and popular press articles. Cockburn *et al.* (2014), based on semi-structured interviews with 53 farmers, concluded that “*experiential learning activities with small, local group of farmers*” and that “*knowledge made available to farmers in a hands-on manner with an emphasis on locally oriented field days and model farms*” was preferred for promoting the adoption of integrated pest management. Similarly, demonstration plots were used to upskill small scale farmers, expand area under production and thereby increase sugarcane production (tons/ha) by 47 % in a smaller localised area, where extensive prior capital investment with comprehensive planning and implementation of projects had failed (Gillespie *et al.*, 2012).

4.2 Narrative Data

Narrative data provides a window to view mental models. The beliefs, assumptions and operating or decision rules become apparent. Narrative data was collected via semi-structured interviews with farmers in the case study area and with extension specialists. In addition, observations were made and mental notes taken during various farm visits, irrigation working group meetings, conferences and workshops.

4.2.1 Narrative data from farmers in the case study area

The narrative data from exploratory interviews with the growers in the case study area reaffirmed, independently, that word of mouth with peers and on-farm testing featured prominently as a knowledge gathering and confidence building activity prior to making the adoption decision. An excerpt of the narrative data is presented below:

Grower A (early adopter):

Question: You have a well thought out and sophisticated irrigation system. How would it all have come about?

*Answer: “**You talk to other fellow farmers. You talk to the guys who design the systems and see what the latest trend is. So the latest trend now is subsurface drip. So now you have to ask, is this for me? And you say nah, with my management style and with this and with that - nah. Or you give it a go, which I have done. I gave this system a go. And you decide, my management is not top notch or my water is dirty. It isn’t going to work for me. It works for that guy, but not for me. You definitely try different things and see what works for you and if the system really works for you - well you go with it**”. You pay the school money” (school money refers to the costs associated with learning from an on-farm testing exercise).*

*“I don’t know if you are familiar with the floppy system. As a point to confirm what I am saying, I also tried that out. I had about 15 – 20 ha and it didn’t work for me. So I threw it out. **It cost me a bit of school money.** Then I installed a drip system on a big area (20 ha). A very fancy drip system with computers that turned the valves on and off. It didn’t work for me. You got people walking around that interfered with and messed up my valves. The computer got hit every now and then with power surges. There is another system where I tried drip as well and the cane rats gave me a problem. So yes, you make a call. **You pay the school money**”.*

Question: With irrigation systems, you would have tested it out on the farm for yourself, but it sounds like you are not interested in probe technology for irrigation scheduling?

*Answer: “What I would do, typically, because I have a system going. I will **check out the other system and I will talk to other guys who use it. If it works and there is a lot of merit to it, then I will obviously weigh it against my system and I think one of the***

most unwise things is to be stuck in your ways. So if I chat to other guys and in the study group or if you say there is one system you have to check out, then I will and if the neutron probe has to be thrown out, then it will be thrown out.”

Question: How do other farmers decide?

*Answer: “Farmers tend to be very (pause). We call it in Afrikaans, **Tropdiere (herd animals)**, so if one guy, (he paused again). That’s an important point, if one guy plants N41 and it works. And they talk at the golf club or whatever, some guys will plant it **without even thinking. Without doing a plan or research. They will just do it.** The other guys are doing it. If one guy says that Mazda is the best bakkie (van) you can get and he buys it, and then another guy and another guy, then they all buy it. **And the same with irrigation systems. You get followers and leaders.**”*

Grower B (adopts later with the majority):

Question: In investigating newer technology, what is the process?

Answer: “You must do a fact finding mission. It’s the same with these new systems. We must investigate. That’s what I did with this guy (referring to an irrigation advisory consultant). I phoned him and said he must make me a proposition on how I must start with this new system. It’s expensive.

But, you know my friend (referring to a neighbouring farmer who has already adopted) will tell me and he is very happy with it. I phoned up my friend and said you have been with it now for a year and half, are you still happy? That’s what I find out first. Is the system still up and running? Is it operating? Is it done properly? Is it done as it should be? Then I got the green light there – then I phone him up (referring to the consultant) and say let’s talk again.”

Grower C (early adopter):

Question: How do you schedule your irrigation?

Answer: I started with tensiometers. Now I have switched some of the farms over to probes.

Question: How did you learn about tensiometers?

Answer: Chris Barnard (an irrigation training consultant). SASRI got him down here. He took us into the fields with soil profile pits.

Question: Was it easy to adopt?

Answer: I am not scared to ask questions.

Question: Talk me through the process. On day 1, you would have seen the demonstration with Chris Barnard. Then?

Answer: Then I started looking at it. Then I bought some. Two sets. I put them in by myself for the first time.

Question: How did you learn about the probes?

Answer: On a study group. A consultant showed us. Unfortunately, I was not there the whole day. I came later and saw a fellow farmer got them on his farm.

Question: You were using tensiometers. Then you moved to probes. How did that happen? What did you think about to make the decision?

Answer: I said to the consultant, he must come put in a probe and show me how it works. He must give me a demo model.

Grower D (laggard, i.e. late adopter):

Question: If you ever have a problem on the farm, who do you seek advice from. How does it work?

*Answer: **Phone a friend, mostly.** Or talk to the extension specialist. **Normally you would phone a guy who you know has a good business running. I won't ask one guy also, I will ask a couple of guys.***

Question: If there a new developments and technology advancements, how will you get to learn about it?

Answer: In this area I think it's easy. Everyone talks and you will get to hear about it. In meetings and stuff. I don't think it's difficult. In the sugar business especially, the guys talk a lot about what's happening and the latest.

Question: A lot of information sharing and learning comes from fellow farmers. You have recently adopted chemical ripening. How many guys did you speak to and how often before you decided to implement chemical ripening?

*Answer: “No if you know which guys have the highest RVs (Recoverable Value (RV) is an indicator of sugar yields) and know what’s going on (i.e. referring to knowing who is successful), you can listen to a guy. **I will always wait until someone gets success first and then I will see. And also, I will test it first, I won’t just go big**”.*

4.2.2 Narrative data from other relevant individuals in the SA sugarcane industry

The organisational structure of the South African sugarcane industry is relatively well designed. Extension specialists form the knowledge and communication bridge between the scientific researchers and farmers. Extension specialists help to identify research gaps and needs for the research institute, while they simultaneously play the knowledge and technology transfer, and farmer advisory, role. Extension specialists are therefore key individuals in promoting and supporting the adoption of BMPs. In this section, relevant narrative data from extension specialists is presented to reinforce the causal themes explored in the system dynamics models in the next subsection.

The narrative data presented below is from an Extension Specialist who works in a different (non-irrigated) region from the case study area. In this instance, he was sharing in the context of adoption of sugarcane varieties:

*“For me the **best way to transfer a technology across**, and we did it about two weeks ago on a farm, we had a guy who planted a whole lot of varieties on the farm and we drove around on the back of a van from one field to the next just looking at the varieties. And on the back of that van was one of my older growers, who I have been trying to tell him to grow N41 for 7 years now and he hasn’t done it yet. But he drove around and after that visit he said I am planting N41. **That is the best way. When they see another grower doing it and it is working. Then they will adopt it. They have to see it to believe it.** PowerPoint presentations, sitting there saying hey you got to grow N41 and show pretty pictures, that is not enough”.*

Question: “SASRI extension have been active for a long time. Yet, despite this, irrigation scheduling has not been adopted. You do not work in an irrigated area, but from the outside looking in, have you any insights on the way extension works”?

Answer: “Extension has worked to large degree in isolation. When I say isolation, we haven’t even involved millers or the economist in the area. And I think that is vital for any study group, they should be there. Because you can’t just throw in the

technical stuff. You have to put the economics in. At the end of the day, if you cannot convince the guy financially, you are never going to convince him. He is not going to adopt it. If you can't prove the Rands and cents behind your technology, he is not going to adopt it".

A retired extension specialist who worked in the case study area for 7 years was also interviewed. Interestingly, there was no extension in the case study area for 3 years prior to his arrival. Furthermore, in the initial periods, the extension specialist was not well respected by the farmers, mostly because of socio-political reasons. He was an Englishman working in a predominantly Afrikaans speaking community. The extension specialist, therefore, had to work a little harder to win over the trust and confidence of the local farmers. The narratives below aim to share insight on some of the strategies used.

Question: "Can you unpack for me a few stories about farmers who didn't listen to you in the beginning and then slowly came around"?

Answer: "Yeah. Well there are 100s of those but they are not recorded. What I used to do was say, "so you don't believe this". Then I would go with them into a field and say right, which side do you want left or right? And he (the farmer) would say right. And I would say ok, give me two labourers. We will do fertilisers and bits and pieces on this side and you will do it on that side. And I beat them every time".

Question: "So it was demonstration"?

*Answer: "Yup. When he saw it he did tend to change". Once I **proved** it to the people, whatever I was talking about, it could be Smut or Ratoon Stunting Disease (RSD) or Yellow Leaf Syndrome or whatever it was, they would accept it. But some of them would say, John "I like it but you have **not proved** it yet". And sometimes it would take me 5 or 6 months. **Yah, they wanted proof. And any farmer should want proof really.***

This concludes the presentation of narrative data and evidence from literature. The main themes and ideas extracted from the above data are summarised below.

4.3 Summary

Most farmers tend to rely on the opinions and experiences of their peers. Interpersonal communication, phrased as word of mouth, is therefore an important causal force in the farming community.

Farmers are naturally risk averse. Generally, there is doubt and uncertainty about an innovation, especially in the initial phases. Hence, a mechanism to allow for learning and experiencing is necessary. 'Seeing is believing'. On-farm testing emerges as a promising mechanism to allow for such learning and experiencing amongst early adopters.

Learning and personal experience, and word of mouth from peers are not used in isolation. These forces do not, necessarily, work at different points in time, or at different stages in the process. Instead, both are used in conjunction with one another to help the individual formulate an attitude about the innovation and ultimately, to make the decision to adopt or not. It was also apparent that some individuals would favour word of mouth, while others will favour learning on their own, while others still will favour a combination of the two, depending on the individual's characteristics traits. The literature suggests that leader farmers will rely more on testing the innovation for themselves. Since they are usually the first groups to interact with an innovation and word of mouth is usually non-existent. Some narrative data, however, did reveal that leading farmers can learn from family and friends in other farming communities in different parts of the country (narrative data not shown). Nevertheless, word of mouth appears to become most effective after an initial group have tested and proven to be successful with the innovation.

Finally, the characteristic traits of the innovation are also important. The innovation must offer a relative advantage in order to appear attractive to any farmer. No relative advantage appears to render the innovation a nonstarter. Similarly, technical soundness, easy to trial and observability of results were portrayed as important innovation characteristics to assist the farmer overcome any initial doubt and uncertainty.

5. RESULTS (PART 2): A WORD OF MOUTH SYSTEM DYNAMICS MODEL

The themes and ideas from the literature and narrative data, presented in the previous chapter, helped to surface a descriptive model of the adoption process. In this chapter, a formal system dynamics model capturing the word of mouth phenomenon is presented. The structure and logical formulation of the model is first presented, followed by results from simulation experiments.

The diffusion of innovation theory was used as the basis for developing the model structure. The essence of the model, however, is not novel. In the system dynamics fraternity, the Bass diffusion model and the epidemic studies are well known (Sterman, 2000 and Morecroft, 2008). Nevertheless, the word of mouth concept is central in the adoption discussion, and this chapter proves useful to introduce the reader to the graphical language and functionality of system dynamics models. Important fragments of novelty include construction and transparent exhibiting of dynamic cause and effect relationships which differ in strength and influence at different points in time, depending on the state of the system at that point in time.

Although model development normally forms part of the methodology in a research study, in this thesis the model is a dynamic articulation of the results obtained from the interviews and literature synthesis. In this chapter the model is systematically developed by incorporating one concept at a time. The main concepts include: positive word of mouth and adoption, dis-adoption, negative word of mouth and non-adoption and farmers becoming neutral and available for re-adoption of other innovations.

5.1 Conceptualisation and Formulation of the Word of Mouth Model

The natural progression of an individual through the adoption decision making stages forms the basis of a stock and flow framework, illustrated in Figure 5.1. The graphical language of system dynamics models used in this thesis is stock and flow diagrams. Stocks are the square blocks in Figure 5.1, and represent the level of a specific variable. In this case the stocks represent the number of farmers at the various stages of the decision making process. Flows are represented

by the pipelines and flow control valves in between the stocks. The modelling platform dictates that only flows can cause a stock to either increase (inflow) or decrease (outflow).

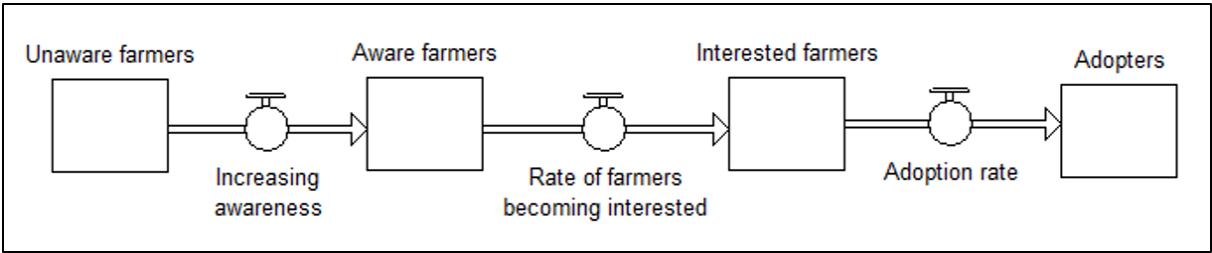


Figure 5.1 Illustrating the flow of farmers through the stages towards adoption

Figure 5.1 depicts the flow of farmers from a group who are simply not aware of an innovation to becoming aware, generating interest and eventually adopting. The units for the stock and the flow variables are number of farmers and number of farmers per year, respectively. In the context of the case study area, baseline data was obtained to determine how the population of farmers were distributed across the stock chain. The extension specialist and the mill sugarcane supply officer, two advisory individuals who live and work in the farming community and know the farming population intimately, provided the current status of farmers with respect to their stage of adoption. In this instance, adoption does not include partial adoption of irrigation principles, which was described by Stevens *et al.* (2005) as intuitive scheduling. Adoption refers to the implementation of a scientific scheduling technology or practice. The distribution of farmers according to the different stages of adoption in the case study area is presented in Figure 5.2.

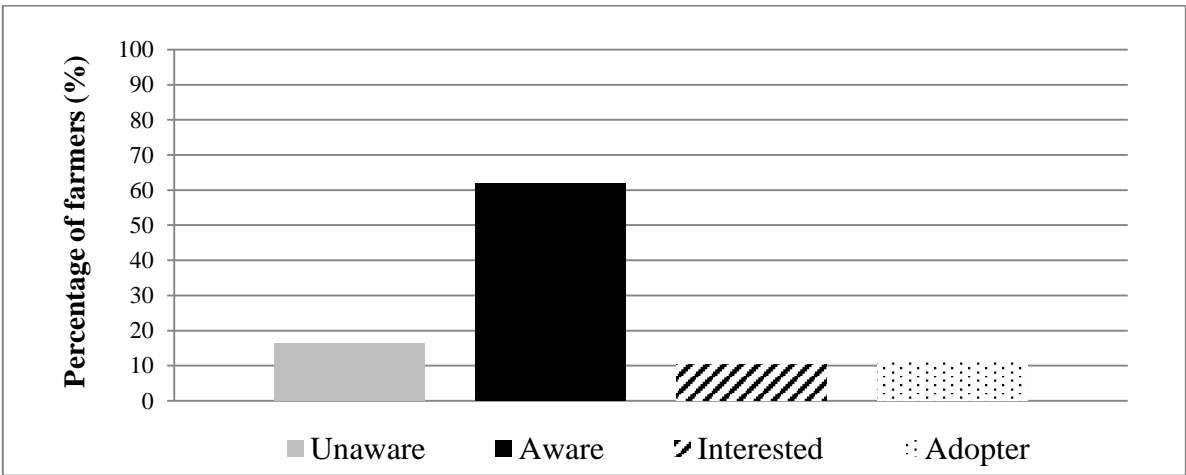


Figure 5.2 Current distribution of farmers in the Pongola Mill supply area

Of the 111 farmers in Pongola, who farm an area of $\pm 16\ 000$ ha, only 11% are adopters of scientific irrigation scheduling technology/tools/methods, with a further 10 % expressing interest. Sixteen percent of the population appears to be totally unaware, while the overwhelming majority of farmers, 61 %, are aware of scientific irrigation scheduling but have not generated any interest in testing or researching the innovations. The data in Figure 5.2 was used to populate the stocks in the model with their respective initial values.

In addition to informing the initial conditions of the model, this data was also useful for focusing where research efforts in model construction should target. Rogers (2003) reported that the most efficient and rapid form of communication for increasing awareness was mass media. Hence, the degree or intensity of mass media will be influential on the rate of flow from the “unaware” stock to the “aware” stock. “Increasing awareness” via mass media was considered out of scope and has not been included in the model. This was on the assumption that “mass media” was effective and well established at SASRI. To some extent, the baseline data in Figure 5.2 supported this. The area of interest in this project was, structurally, how “interested farmers” convert to become “adopters”. This is illustrated in Figure 5.3.

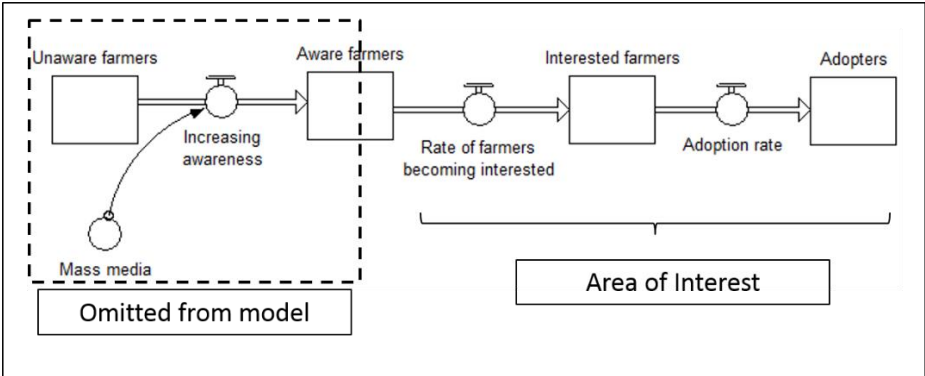


Figure 5.3 Depiction of boundary formulation omitting “mass media” from model

Model fragments dealing with population dynamics in past system dynamics models (Forrester, 1961) were used to conceptualise and formulate the “adoption rate” in the model. In a stock and flow diagram, the curved arrows pointing towards a variable indicate mathematical dependency. As shown in Figure 5.4, the numerical value of the “adoption rate” was defined to be dependent on two variables, the number of “interested farmers” and the “adoption fraction”, i.e. the “adoption rate” was equal to the number of potential adopters (“interested farmers”) multiplied by an “adoption fraction”. Operationally, this means that a fraction of the “interested farmers” in the model will make the decision to adopt every year.

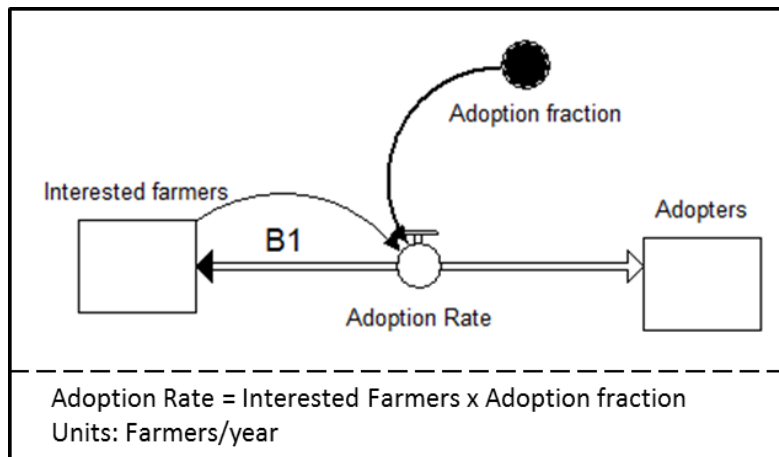


Figure 5.4 Formulating the “adoption rate”

Naturally, the reader should be wondering, what determines the “adoption fraction”? How many “interested farmers” are converted to “adopters” every year? Is the “adoption fraction” the same number every year? As shown in Figure 5.5, the “adoption fraction” is driven by the “effect of word of mouth”, which in turn is a function of the current number of “adopters” (expressed as a percentage of the “total population”). It stands to reason that as the number of adopters increase, the “effect of word of mouth” will increase, thereby increasing the “adoption fraction”, the “adoption rate” and the number of “adopters” even further. This circular feedback gives rise to a positive reinforcement (virtuous) loop labelled R1. Referring back to Figure 2.2, circular feedback is when a change in one variable propagates change in a connected system returning to affect further change in the original variable.

Growth of the adoption “stock”, however, cannot go on forever. A point in time must be reached when all the non-adopters have become “adopters”. This is what the balancing loop B1 captures (Figure 5.5). As the “adoption rate” increases, the “interested farmers” stock is drained, bringing about a reduction in the “adoption rate”. The feedback loop can be thought of as a market saturation loop, since, as the stock of “adopters” increase, the stock of “interested farmers” will be drained until there are no more “interested farmers” available to “adopt”. In system dynamics, a balancing loop is also described as a goal seeking loop. In this case, the goal seeking feedback loop aims to drain the “interested farmer” stock to zero. The combination of feedback loops R1 and B1 was expected to deliver the classical Sigmoidal (S-Shaped) behaviour mode typically associated with innovation diffusion (Sterman, 2000; Rogers, 2003 and Morecroft, 2008).

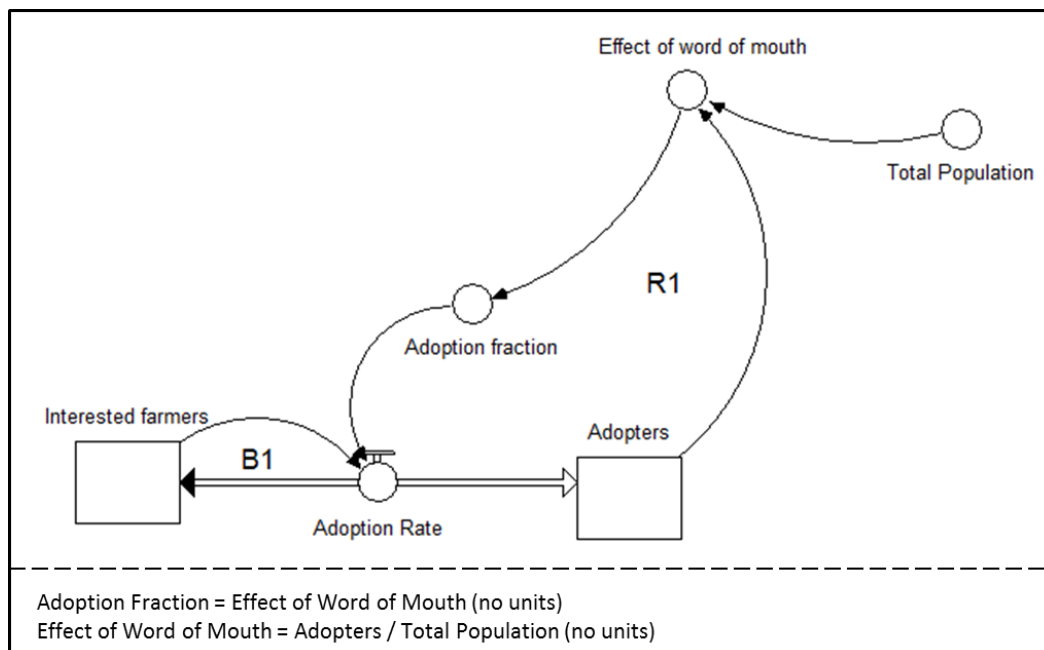


Figure 5.5 Formulating the “adoption fraction”

Figure 5.5 can also help to introduce the reader to the system dynamics term ‘causal structure’. The causal structure refers to the fact that the resultant behaviour is a function of the feedback loops acting on the flow variables which dictate the behaviour of the stocks. The feedback loops in turn are a function of the variables and the manner in which they are connected to each other, i.e. the structure of the system. Hence, the connectivity gives rise to the underlying structure which in turn dictates the behaviour (Richardson, 2011). In Figure 5.5, the underlying causal structure is made up of the feedback loop R1, which drives adoption via an effect called word of mouth, and the feedback loop B1, which restricts adoption via the drainage of potential adopters (“interested farmers”). In essence, a causal structure with two opposing forces.

The stock and flow chain, illustrated in Figure 5.6, was extended to include the “aware farmers” stock and the “farmers becoming interested” flow. Similar to the “adoption rate”, the “farmers becoming interested” (flow variable) was represented as a fraction of the number of “aware farmers”. As shown in Figure 5.6, the fraction of “farmers becoming interested” is driven by the “effect of word of mouth”. Hence, the word of mouth and saturation feedback loops are also extended as depicted by the labels R2 and B2 in Figure 5.6.

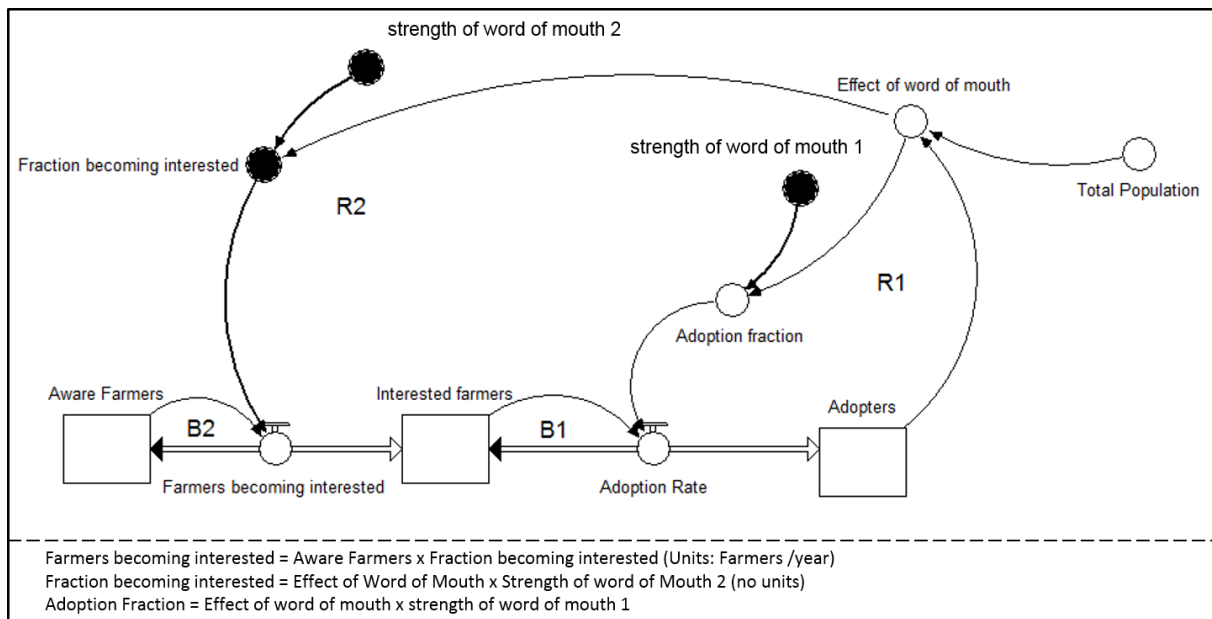


Figure 5.6 Stock and flow chain with word of mouth and saturation feedback loops

Intuitively, when thinking of the real world, the existing adopters will probably find it easier to stimulate interest amongst the aware farmers through word of mouth as opposed to convincing a farmer to adopt. In other words, it is expected that “effect of word of mouth” will be stronger when acting through the “fraction becoming interested” variable as compared to the “adoption fraction”. For this reason, the “strength of word of mouth” variables, 1 and 2, were introduced. Both the strength of word of mouth variables are adjustable between 0 – 1, and allows for modulating the strength of the “effect of word of mouth” signal to the respective fraction variables. Data about the “strength of word of mouth” was not readily available or easy to detect. Nevertheless, it is better to represent this in the model and make the simplified assumptions transparent and available for scrutiny and learning, as opposed to omitting them from the model due to lack of data (Sterman, 1994). Herein lies one of the main strengths of system dynamics modelling. In the absence of data, and based on intuition, the “strength of word of mouth” variables 1 and 2 were set to 0.3 and 0.5, respectively.

A preliminary base run of the above model fragment was simulated to see if the results would match the anticipated S-shaped mode of behaviour. The case study area, Pongola, was used to populate the initial value of stocks in the model. In the computer simulation exercises, reported from this point onwards, the total number of farmers was rounded down from 111 to 100. The initial values of the stocks are shown below.

Aware farmers = 80 farmers
 Interested farmers = 15 farmers
 Adopters = 5 farmers
 Total population = 100 farmers

The simulated result for each stock is shown in Figure 5.7 below.

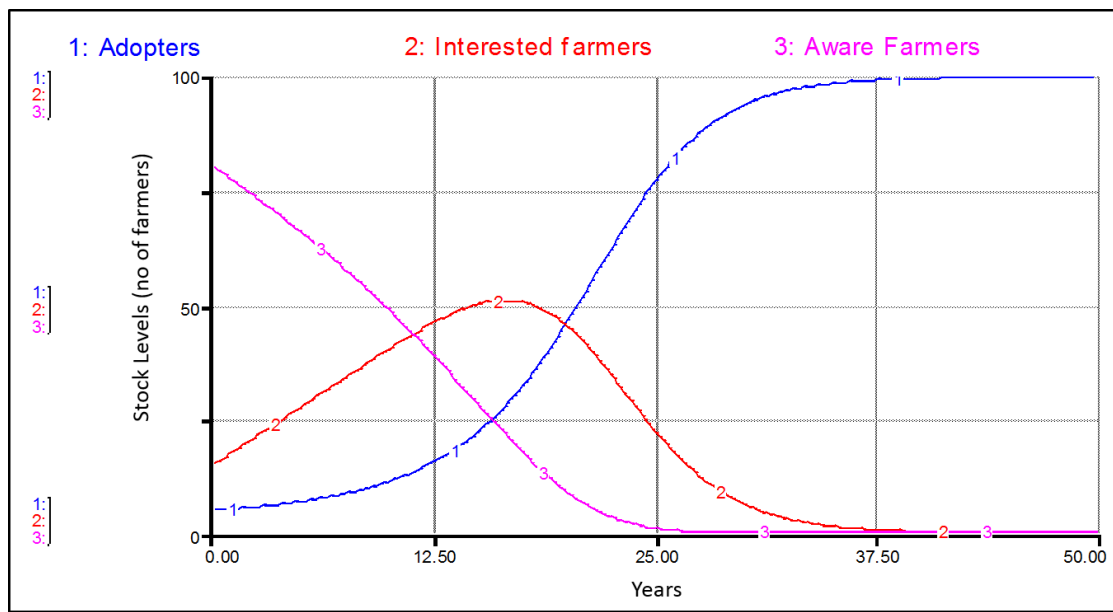


Figure 5.7 Simulated baseline results

The simulation output of a system dynamics model is a behaviour over time graph. In Figure 5.7, time (years) is represented on the x-axis and the levels of the different stocks (units: number of farmers) on the y-axis. As anticipated, the adopter curve exhibited the s-shaped mode of behaviour. The positive word of mouth feedback loop drives the growth of the “adoption” stock in a compounding manner initially, until the balancing saturation feedback loop begins to dominate, shaping the “adoption” stock curve to a goal seeking behaviour mode in the later stages.

The model structure in Figure 5.6, dictates that the stocks are connected and dependent on each other. Hence the behaviour of one variable in Figure 5.7 can be used to explain the behaviour of another. The change in the “interested farmers” stock level provides an indication of the net flow. A net increase in the “interested farmers” stocks, indicates that the inflow was greater than the outflow at that point in time. Hence, a net inflow into the “interested farmers” stock is associated with an outflow from the “aware farmers” stock, as depicted between year 0 and

year 15, i.e. the decrease in the “aware farmers” stock results in an increase in the “interested farmers” stock, when the outflow to adopters is low. In between years 15 and 25, the “interested farmers” stock declines, despite the inflow from “aware farmers”. Hence, the net outflow of “interested farmers” corresponds with the increase in the “adopters” stock.

Over and above explaining the systemic connectedness of variables, the behaviour over time graphs also help to reflect upon expectations in the real world. In Figure 5.7, the “adopter” stock, initially, increases gradually with only 7 farmers adopting after 5 years (2 additional from the initial 5 farmers). In the real world, if only 2 additional farmers have adopted after the first five years, an individual’s mental model might suggest that the case is hopeless, causing, say, an extension specialist to give up hope! The simulation results further reveal that when the “adopter” stock level accumulates to a critical mass of 22 farmers, achieved in year 15, the “effect of word of mouth” appears to kick in. After year 15, the “adopter” stock level rapidly rises, reaching 77 farmers in the next 10 years (year 25) and virtually all farmers by year 35.

At this point, it is important to acknowledge that the model is not configured or populated to be predictive. Instead, the model is demonstrative. Hence, the numbers and timelines are not necessarily to be taken as representative of reality. The results in Figure 5.7 suggest that if enough years pass by, all farmers in the community will adopt. This result is not realistic, confirming that the model is flawed. Nevertheless, the model is still useful for questioning reality and expectations of reality. In this case, when the “strength of word of mouth” variable was set to 30%, the “adoption” stock took 15 years to accumulate 22 farmers. One can use this to introspect and perhaps speculate on the patience required by extension specialists, in the early phases of any innovation before word of mouth can become effective. Similarly, robust debate can be stimulated to test the mental models in terms of what % of the population can or should adopt?

5.1.1 Preliminary consideration of pathways to improve adoption

In this section, structural pathways to improve the rate of irrigation scheduling adoption are explored through further model development and simulation. From the many conversations with project team members, extension specialists, farmers and interested spectators (i.e. observation and narrative data), the movement of farmers from the “aware farmers” stock to the “interested farmers” stock seems to be hinged on how highly ranked water management is on the priority

list. When water management is a low priority, then non-adoption is blamed on ‘excuses’ such as: there is not enough time, the innovation is too complicated, it is too expensive and the benefit is not big enough. In the literature, these factors have traditionally been captured as barriers to adoption (Stirzaker, 2006). We know they exist and are often quoted as the reasons for non-adoption (or slow adoption). The logic for this model fragment, however, is that when water management is a high priority, farmers quickly become interested and may even go on to adopt. A logical question to ask is what causes a farmer to make water management a high priority.

It appears, for example, that when water is the limiting factor and is drastically reducing production or profits, then water will be more important in the minds of farmers. This mindfulness is expected to make farmers proactive and/or more receptive to irrigation scheduling. A recent example includes the drastic increase in electricity tariffs which substantially impacted on the cost of irrigation and profit margins. This example illustrates how farmers can suddenly become sensitive to irrigation management, paving the way to faster adoption.

This concept was incorporated into the model by introducing a variable titled “effect of priority change”. The intention was to model how behaviour changes in the presence of a change in priority. The model structure with the new variable is shown in Figure 5.8.

The “effect of priority change” was connected to the “effect of word of mouth”. The “effect of priority change” is a switch that can vary in strength, between 0 - 100. The equation in Figure 5.8 shows the mathematical formulation for the effect of priority change switch. When the “effect of priority change” is set to the maximum value of 100, the “effect of word of mouth” is doubled. When the “effect of priority change” is set to 0, the “effect of word of mouth” retains the original formulation, where “effect of word of mouth” is a function of the existing number of adopters expressed as a percentage of the “total population”. It is important to note that the additional causal link does not add more feedback loops to the model structure.

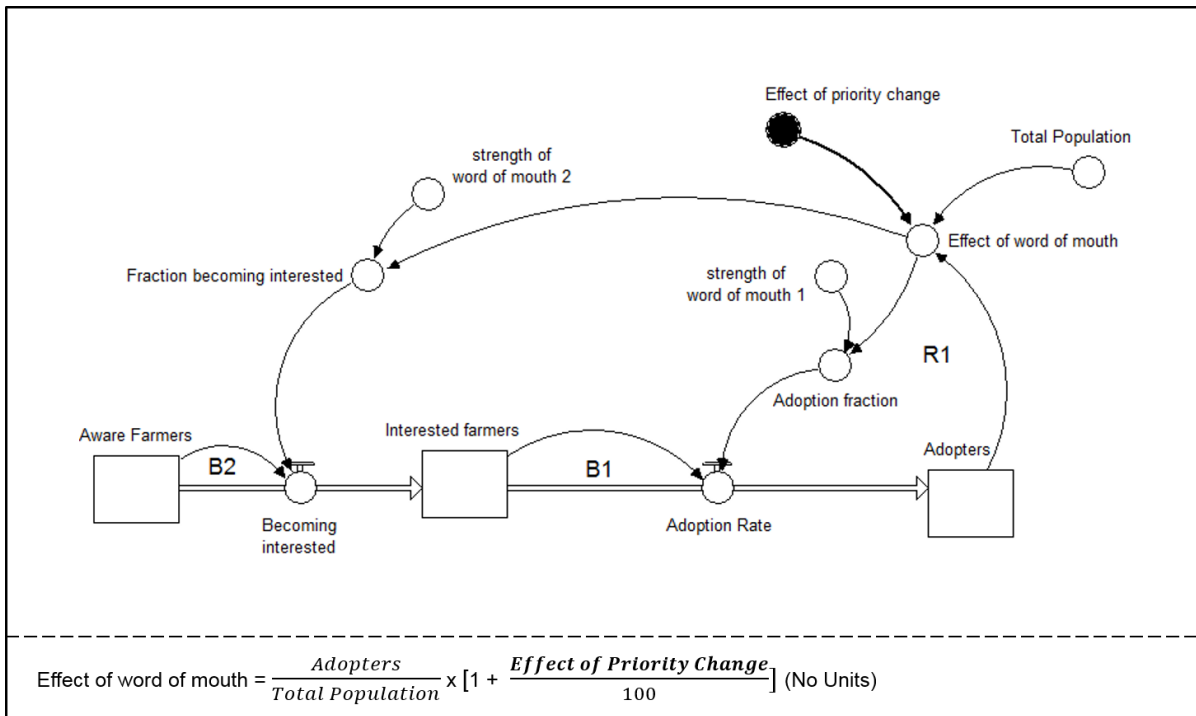


Figure 5.8 Model structure incorporating the “effect of a priority change”

Hence, both the mathematical formulation and logic dictate that when the “effect of priority change” switch is activated, it is expected to have an amplifying “effect on the word of mouth” feedback loops R1 and R2. In other words, when water is relatively unimportant, the adopter farmers are only able to influence a certain percentage of the non-adopter population via word of mouth. When rapid electricity tariff increases, for example, make water a more important variable, the adopter farmers are able to influence a larger proportion of the non-adopter population, for the same word of mouth effort. Figure 5.9 reflects the preliminary result when the “effect of priority change” is activated (set to 100).

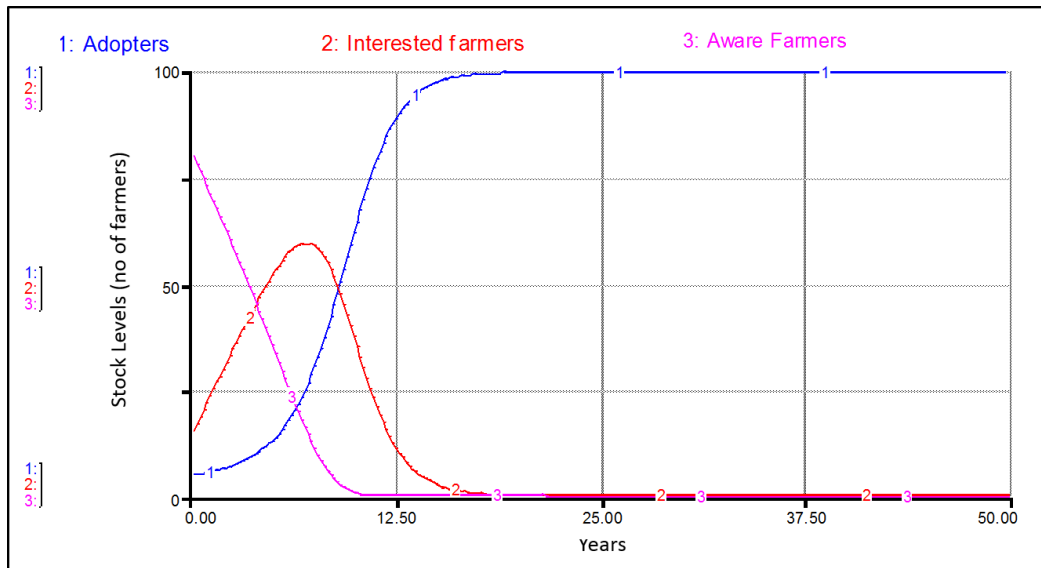


Figure 5.9 Improved speed of adoption due to priority change

As expected, the amplification effect of the priority change on feedback loops R1 and R2 substantially increased the speed of adoption. The time to reach the 22 and 77 “adopter” stock levels was 6 and 11 years, respectively, compared to the 15 years and 25 years in Figure 5.7.

5.2 Extending the Innovation Diffusion Model to Incorporate Negative Word of Mouth

Following conceptualisation and formulation, the word of mouth model and accompanying narrative data was shared with the extension specialists in the case study area. The intention was to firstly, gain confidence that the model was representing the adoption process correctly and, secondly, to identify missing influential forces/feedback that should be represented in the model. During the model sharing exercise, the following narrative data was obtained from the extension specialists.

Question: What is missing from the model? What forces at play are not shown?

Answer: Extension Specialist 1:

*“If you think about the process of adoption, the **confirmation support**. The **sounding board** has to be there. That will be stronger than word of mouth and priority change. I will use ripeners as an example. The guys will continuously contact us and ask: do you think I should do it now? Should I ripen this? Or why haven’t I seen the effect of the ripener? The process is going, word of mouth is working, but, in any agricultural systems, it is not flawless. You will have problems. You will have hiccups. And explaining the problems, why*

*they are there, what the hiccup is, **preventing the negative feedback** is important. **Extension is a lot about being the sounding board. Am I doing the right thing? Where should I tweak it? First you give information to create awareness. That first awareness is from an external source like us. Then it's about strengthening and ironing out the problems. It's giving logical explanations.***

Extension Specialist 2:

*When you get to adoption, it doesn't stop there. **You have to keep these guys (adopters) happy, because they will have a negative influence on the rest of the guys.***

Question: What label would you give this?

Answer: Extension specialist 2: Information and technology support.

*Extension specialists1: **"Extension support"**.*

Insight about the importance of extension support in the adoption process was gained from the above narratives. The role of extension, to reassure growers when problems or uncertainty about an innovation arises, appears to be invaluable. The narratives also suggest that extension support was necessary to minimise dis-adoption and the subsequent effect of negative word of mouth. The disgruntled dis-adopters, may very well go on to negatively influence potential adopters, both preventing adoption and causing interested parties to become uninterested. Hence, the narrative data creates the impression that extension specialists have to split the time and effort between keeping existing adopters happy and encouraging potential adopters to adopt. These key points provide a good example of the value of sharing transparently the assumed structure and forces at play in the system. In this case, the extension specialists pointed out missing feedback in the model (negative word of mouth), which was obviously critical and problematic in their everyday realities.

As a result of the above interactions, the model was refined to incorporate dis-adoption, negative word of mouth and extension support. An outflow from the adopter stock to a new "disgruntled farmers" stock is introduced in Figure 5.10. The outflow, "dis-adoption rate", represents the process of dis-adoption. The "dis-adoption rate" is a product of the number of "adopters" and a "dis-adoption fraction", i.e. some fraction of the "adopters" become dis-adopters every year. The factors used to determine the "dis-adoption fraction" are discussed later, on page 71 (Figure 5.14).

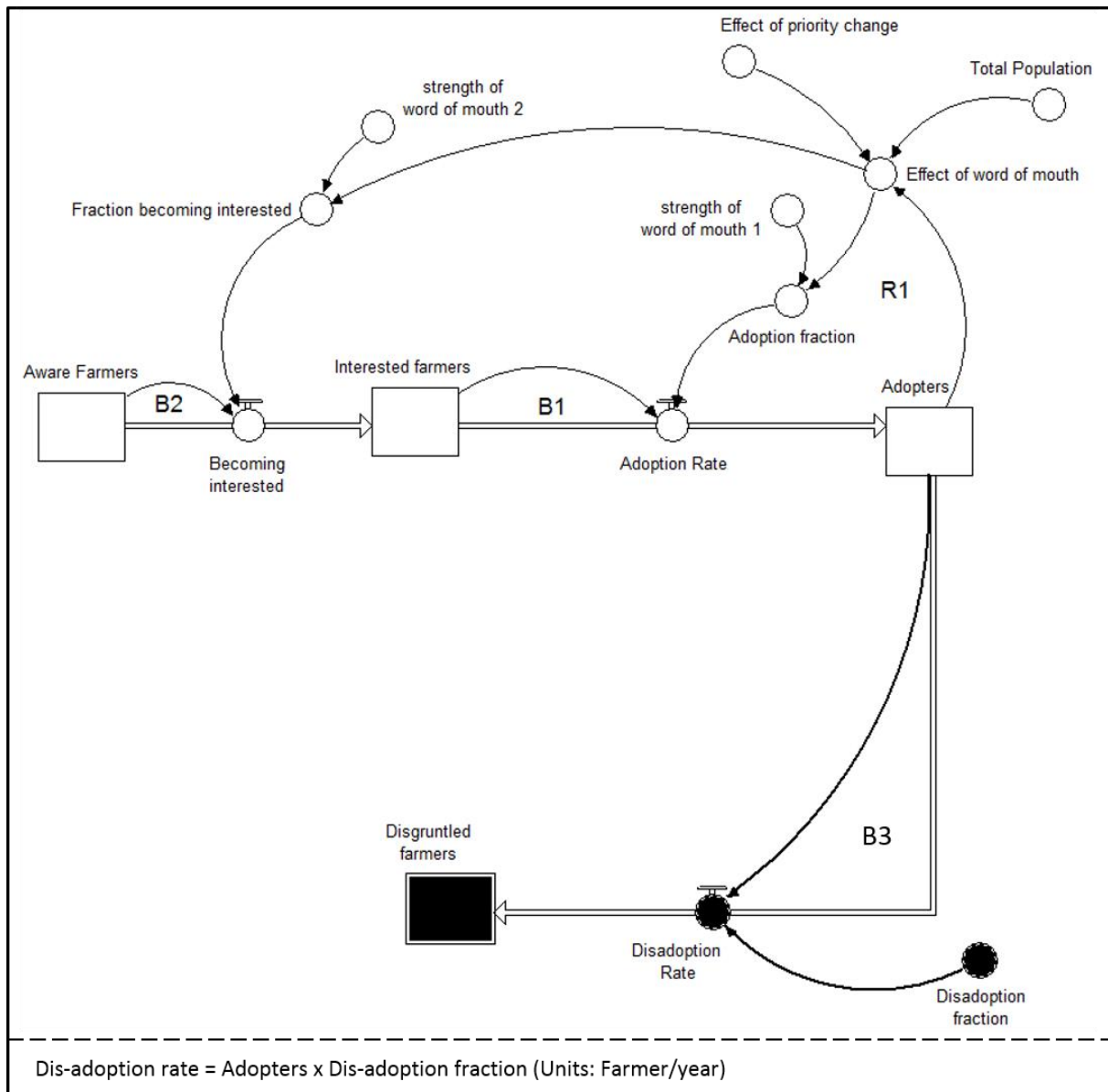


Figure 5.10 Introducing dis-adoption

The “dis-adoption rate” is driven by a balancing feedback loop B3, similar to B1 and B2. As the number of “adopters” increases, the “dis-adoption rate” will increase, which in turn will reduce (drain) the number of “adopters” in the adopter stock.

Figure 5.11 illustrates the origins of the influence of “negative word of mouth”. Intuitive logic and the narrative data suggest that dis-adopters who now sit in the “disgruntled farmers” stock will be disillusioned about the innovation. Hence, these farmers are deemed to be the original source of “negative word of mouth”.

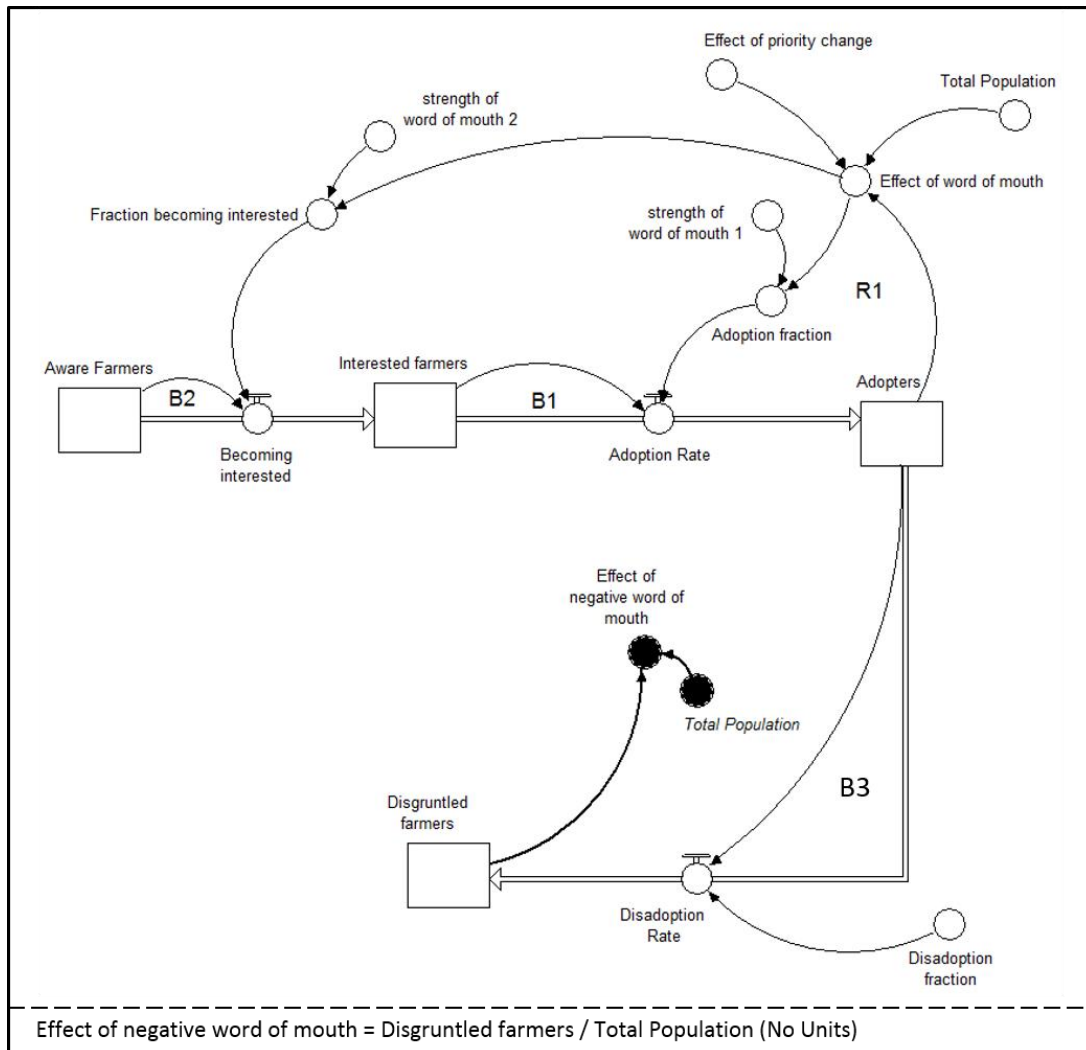


Figure 5.11 Introducing the origins of the “effect of negative word of mouth”

In Figure 5.11, the “effect of negative word of mouth” is determined by the number of farmers in the “disgruntled farmer” stock, expressed as a percentage of the “total population”. In other words, the “effect of negative word of mouth” increases as the number of dis-adopters increase. Figure 5.12 illustrates how negative word of mouth can stimulate an erosion of the “interested farmers” stock via the flow “losing interest”. The “losing interest” flow is calculated as the number of “interested farmers” multiplied by the “effect of negative word of mouth” and the “strength of negative word of mouth”. Not only does losing interest drain the “interest farmers stock”, which is the stock of potential adopters, but it also fills up an “uninterested farmers stock”, which is available to further contribute to the “effect of negative word of mouth”. A double blow. Please note, the “total population” illustrated with a dashed circle in Figure 5.12 is exactly the same variable as the “total population” with a solid circle. The variable is simply

duplicated and re-positioned for neatness. This is applicable to all variables appearing with the dashed circles.

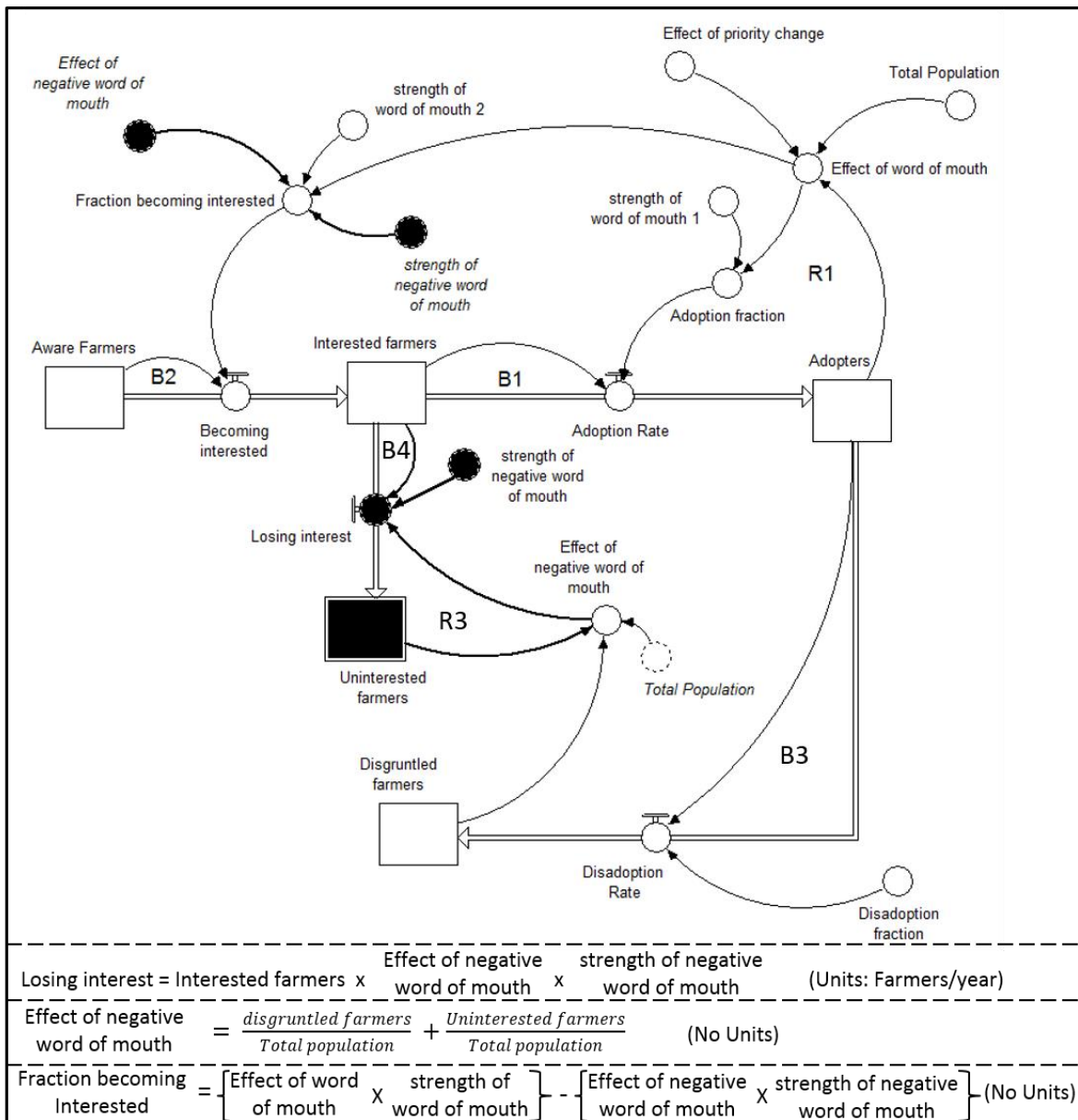


Figure 5.12 Illustrating the structural entry point for the “effect of negative word of mouth”

Similar to previous formulations (“aware farmers” stock, for example), the behaviour of the “uninterested farmers” stock is governed by two feedback loops. The first is a reinforcing feedback loop (R3). In this feedback loop, as the number of “uninterested farmers” increase, the “effect of negative word of mouth” increases which will increase the “losing interest” flow rate, which further increases the “uninterested farmers” stock. The second feedback loop is a balancing feedback loop (B4), which is similar in nature to the saturation balancing loops B1

and B2. Hence the “uninterested farmers” stock is expected to follow the sigmoidal (S-shaped) mode of behaviour.

Furthermore, the ability of a dis-adopter to negatively influence (persuade) an “interested farmer” (who is a potential adopter) is variable and difficult to estimate. It is conceivable that the dis-adopter won’t always be successful in discouraging a potential adopter. Hence, the “strength of negative word of mouth” variable was introduced to capture the likelihood of success/failure of the “effect of negative word of mouth”. The “strength of negative word of mouth” variable is exactly the same as the previous “strength of word of mouth 1 & 2” variables. Previously, it was conceived that positive word of mouth would be stronger to generate interest amongst farmers when compared to encouraging adoption. For this reason, “strength of word of mouth 1” and “strength of word of mouth 2” was set as 0.3 and 0.5, respectively. In the absence of data, and based on intuition, the “strength of negative word of mouth” was also set at 0.5. The explicit assumption is that the likelihood of farmers becoming interested in an innovation when speaking to existing adopters is the same as the likelihood of farmers to become negative and discouraged when speaking to dis-adopters. Adoption from merely speaking to a peer farmer is even less likely.

Also, as can be expected, the “effect of negative word of mouth” will influence the “fraction becoming interested”. Remember the “fraction becoming interested” represents the number of “aware farmers” who become interested every year. Previously only positive word of mouth influenced the fraction becoming interested. In this refined model, however, the “fraction becoming interested” is now the difference between the effects of positive word of mouth from satisfied adopters and the “effect of negative word of mouth” from disgruntled dis-adopters.

There are two important points to take note of. Firstly, the “effect of negative word of mouth” undermines adoption in two ways. It introduces a competing outflow from the “interested farmers” stock depleting the number of farmers available to adopt. It also hinders the inflow into the “interested farmers” stock by acting on the “fraction becoming interested”.

Secondly, the “effect of negative word of mouth” can be driven by both “uninterested farmers” and “disgruntled (dis-adopter) farmers”. Studying the model structure in this way allowed the researcher to surface and make explicit the assumption that, non-adopter farmers who have become uninterested and farmers who adopted but later changed their minds and dis-adopt,

have the same strength of influence via the “effect of negative word of mouth” variable. “Uninterested farmers” don’t necessarily have to experience the innovation for themselves in order to churn out negative word of mouth. In other words, negative word of mouth can be influential, irrespective of whether it is based on truth (real life experiences) or not.

With this in mind, recirculating flows are introduced allowing for both “uninterested” and “disgruntled farmers” to become neutralised after a passage of time. The “neutralising” flows are introduced in Figure 5.13. “Neutralising” refers to the process where the farmers’ inner attitude about the innovation changes. The farmers stop contributing to the “effect of negative word of mouth”. Hence, the flow of “neutralising” and “becoming neutral” allow farmers back into the “aware farmers” stock, with the possibility of becoming interested in the innovation again. The author acknowledges that these are complex psychological processes and the model structure here is simplified for functional purposes. In the model, no explicit causal factors are shown to drive the “neutralising” process. Instead, in a simplified assumptive manner, “neutralising” was assumed to be a natural process which occurs as time passes by. The model does, however, differentiate between the time it takes for an uninterested farmer to neutralise, versus the time it takes for a disgruntled farmer to become neutral. Data about the “time to become neutral” is not readily available or easy to detect. Similar to the “strength of word of mouth” variables, it was considered better to represent these variables in the model and make the simplified assumptions transparent and available for scrutiny, as oppose to omitting them from the model due to lack of data.

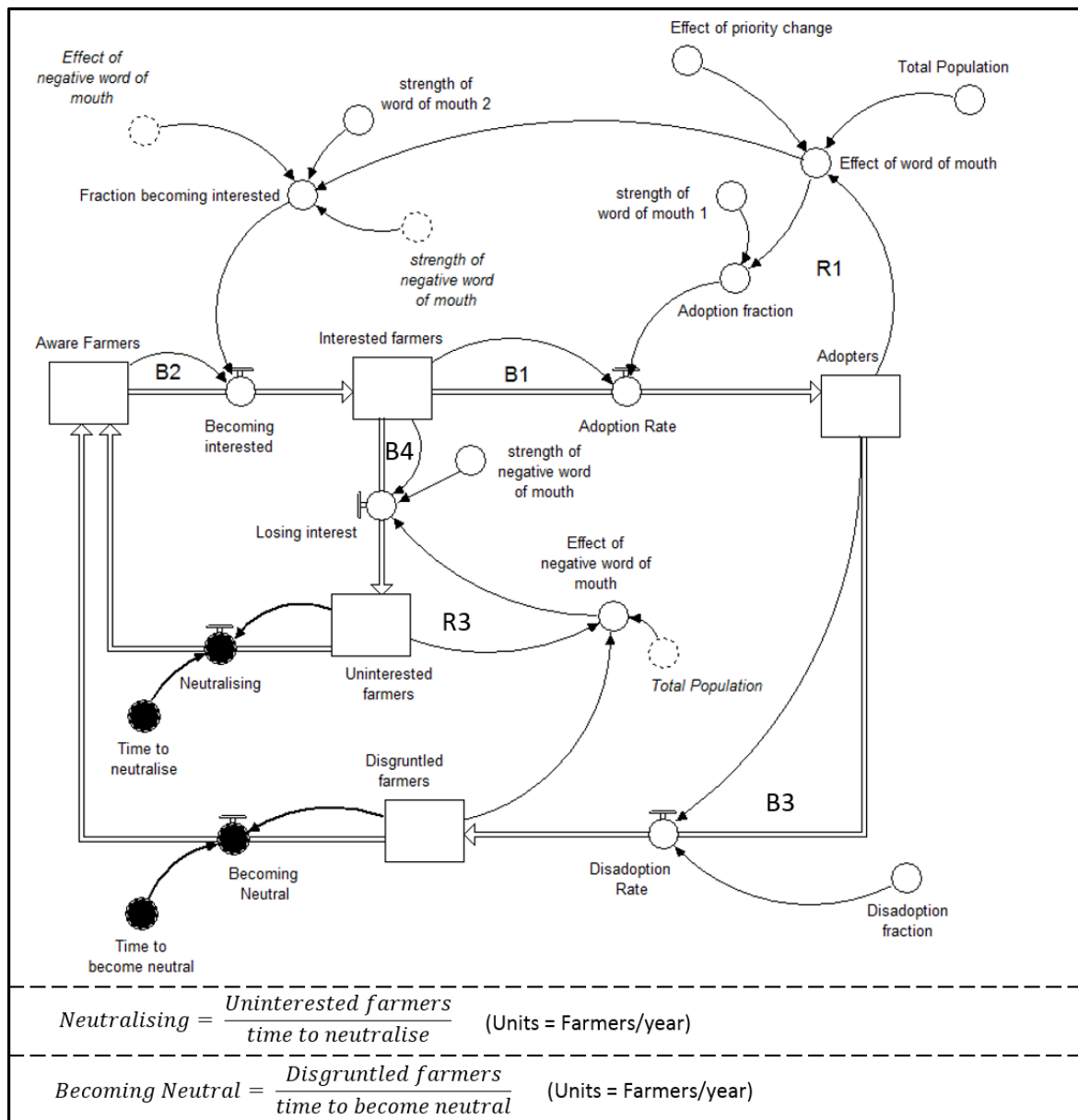


Figure 5.13 Recirculating farmers from negatively inclined stocks back to neutral

It is worth pointing out that the reality in the case study area is that there are not many farmers in the “disgruntled farmers” stock. There has not been widespread dis-adoption of any irrigation scheduling innovations. There may, however, be one or two dis-adopters spreading the “effects of negative word of mouth” and stimulating the flow of “losing interest”. It is likely that this has gone by unnoticed or perhaps is not something that is explicitly measured by extension specialists and agents of technology transfer.

Reflecting on the model structure, it is important to note that the trigger for the reinforcement feedback loop R3 is dis-adoption. If “adopters” do not become disillusioned and dis-adopt, negative word of mouth will potentially not arise. Dis-adoption is the origin of negative word

of mouth. So the question is what causes dis-adoption? In modelling terms, how can one quantify the “dis-adoption fraction” and how does it change over time? As shown in Figure 5.14, this component was next built into the model.

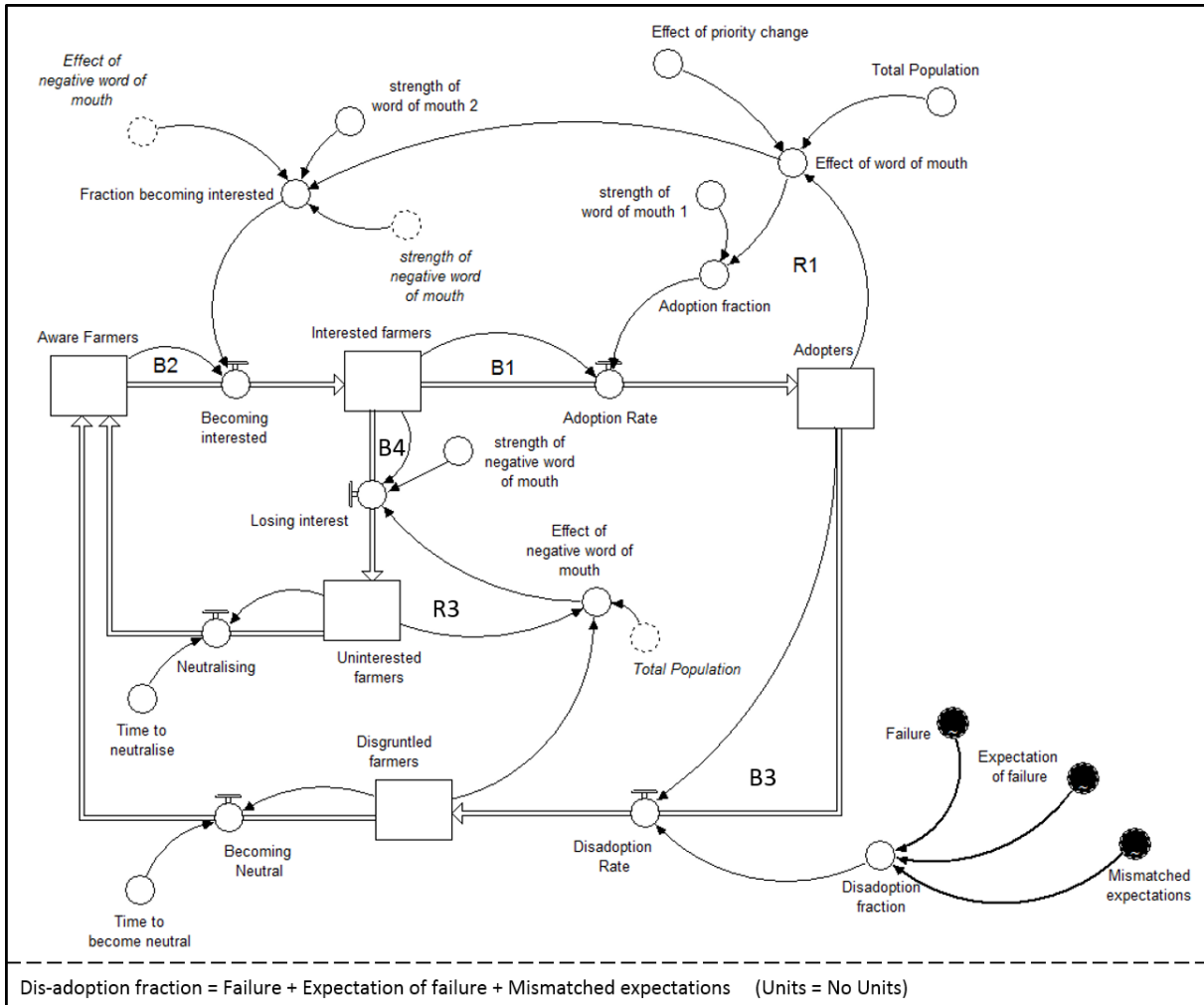


Figure 5.14 Causal variables contributing to the “dis-adoption fraction”

The “dis-adoption fraction” dictates what percentage of “adopters” become “disgruntled farmers” (dis-adopters) in any given year. In the absence of data, the “dis-adoption fraction” was linked to three causal variables, namely, the fraction of farmers who dis-adopt due to “failure”, “expectation of failure” and/or “mismatched expectations”. The logical and descriptive explanations for this model fragment is as follows. If an individual finds that a new innovation is failing (not working), the individual will most likely dis-adopt this innovation. Similarly, if an individual finds that an innovation is failing on neighbouring farms, there is every chance that the individual will also dis-adopt even before the innovation has failed on his farm. The “expectation of failure” may force the individual to cut their losses and prevent any

further investment of time and energy on the innovation. Finally, “mismatched expectations” refers to a case where the innovation is not delivering what the individual was expecting. Hence, since the innovation is not delivering what the individual thought it would, dis-adoption is also a likely outcome. The model structure here aims to capture and represent the directional influence of the causal factors. The author acknowledges that this is, again, a simplification of complex psychological processes. The simplified representation, however, allows the variables to become operational as opposed to being omitted. In this light, it was also important to represent “failure”, “expectation of failure” and “mismatched expectations” as dynamic, not static, variables. “Failure”, for example, is not the same at all times for all states of the system. The likelihood of “failure” at one point in time is different from the likelihood of “failure” in a different point in time i.e. the strength of the “failure” variable, and its propensity to induce dis-adoption, is a function of the state of the system at that point in time. The novelty and power of system dynamics modelling, lies in the construction of mathematical input relationships that propose explanations of causality and/or dependency amongst variables. Two examples of graphical relationships are shown in Figure 5.15, Part A and Part B. The graphical relationships illustrated in Figure 5.15 were conceptualised by the author and manually graphed into the system dynamics modelling software via the input screen shown in the figure. In the software, the input graphs can easily be reshaped, by clicking and dragging the points on the curve to new positions. Note, only one of the two graphs in Figure 5.15 will be used at any given time. The discussion in the paragraph below is presented to exhibit the functionality and flexibility of the graphical input function.

Two intuitively logical relationships were formulated between the “failure” variable and the number of “adopters”. In the first instance, logic suggested that when the number of “adopters” was low in the real world, the innovation was new and relatively untested/unproven, making the innovation most susceptible to failure at this stage. As the number of “adopters” increased, however, teething problems were expected to become ironed out and peer support strengthened making the opportunity for failure small. This relationship is depicted in part A of Figure 5.15. Note, this relationship is an input function dictating what value should be used as an input for the “failure” variable at a specific time step, for the corresponding state of the system at the same time step. For example, when the number of “adopters”, expressed as a fraction of the “total population” is low, say 0.3, then the corresponding value for “failure” is 0.14. This implies that 14% of the adopters can experience “failure” and dis-adopt at that point in time. As the fraction of “adopters” increases to beyond 0.5, however, “failure” was assumed to

disappear. Also, “failure” was never allowed to be greater than 0.2 (maximum value on y axis). The models was configured such that the fraction of farmers dis-adopting due to “failure” was never greater than 20% of the existing number of “adopters”.

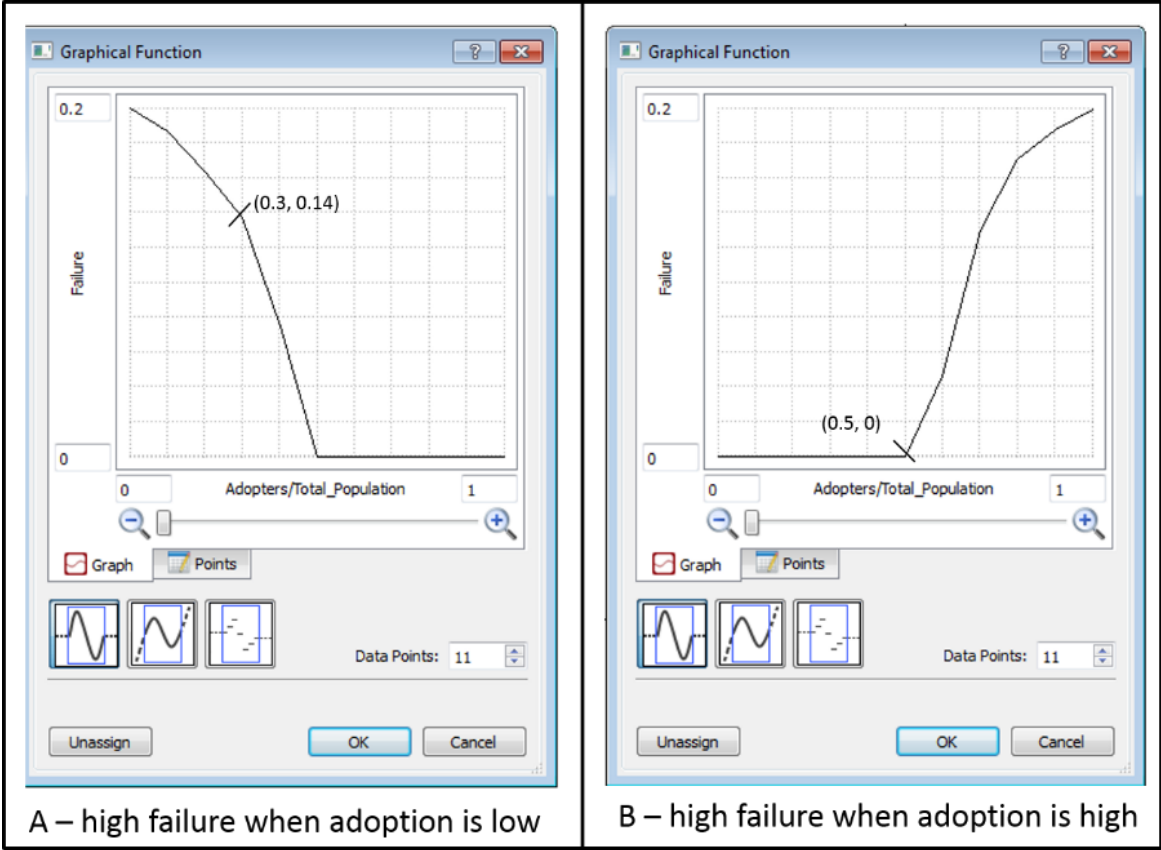


Figure 5.15 Non-linear graphical relationships between “failure” and the number of “adopters”

An alternative relationship is shown in Part B of Figure 5.15. In Part B of the figure, “failure” is zero when the fraction of “adopters” is low (< 0.5). “Failure”, however, starts to increase rapidly when the fraction of “adopters” increases above 0.5. The explanation for this relationship, in terms of the real world, is equally logical and intuitive. When the number of “adopters” is low, it was assumed to be easy for extension specialists and product representatives to provide dedicated and customised support to prevent/minimise “failure”. As the number of “adopters” increase, however, the time and effort required to provide the same levels of support is difficult, if not impossible. Hence, the likelihood of “failure” becomes larger when the number of “adopters” is high.

It is important to note that both of the above-mentioned input relationships do not necessarily explain the causes of “failure”. Instead, they merely ensure that the relative strength of “failure” is appropriately represented according to the state of the system. There are two reasons for spelling out the above possible relationships between “failure” and the number of “adopters”. Firstly, to demonstrate that the simulation platform allows for easy capturing and transparent communication of the relationships. In addition, switching and testing of the different relationships in different simulation experiments is easy. Each individual relationship can be easily modified in the software by adjusting the shape of the curve, depending on signals or data obtained from the real world.

Secondly, transparent exposition of these non-linear graphical relationships help to frame problem statements, research needs and ultimately grow an appreciation of the dynamic complexity. In this instance, it was not known which relationship better reflected reality. It was plausible that the first relationship may apply for a certain type of innovation (soil moisture probes, for example), while the second relationship was more applicable to another innovation (say irrigation scheduling computer models). Or that the different relationships may apply in different case study areas. It was also possible that the social dynamics and culture of the community may evolve and change such that the non-linear graphical relationship (A or B) was applicable at one point in time, but not at a different point in time. The system dynamics platform allows for transparent construction and robust scrutiny and debate on the assumed/proposed causal relationships. Again, in the absence of data, and for the purposes of this thesis, the relationship in part A of Figure 5.15 was used in an exploratory manner.

The complex psychological (causal) agents of dis-adoption were presented in a simplified manner as “failure”, “expectations of failure” and “mismatched expectations”. The variables which were used to calculate the strength of the individual components (“failure”, “expectation of failure” and “mismatched expectations”) is shown in Figure 5.16. The figure illustrates that the strength of the “failure” variable is dependent on the number of “adopters”, expressed as a fraction of the “total population”. Similarly, the “expectation of failure” was assumed to be a linear function of “failure”. In other words, when “failure” was high, “expectation of failure” amongst neighbouring farmers was also expected to be high, and vice versa.

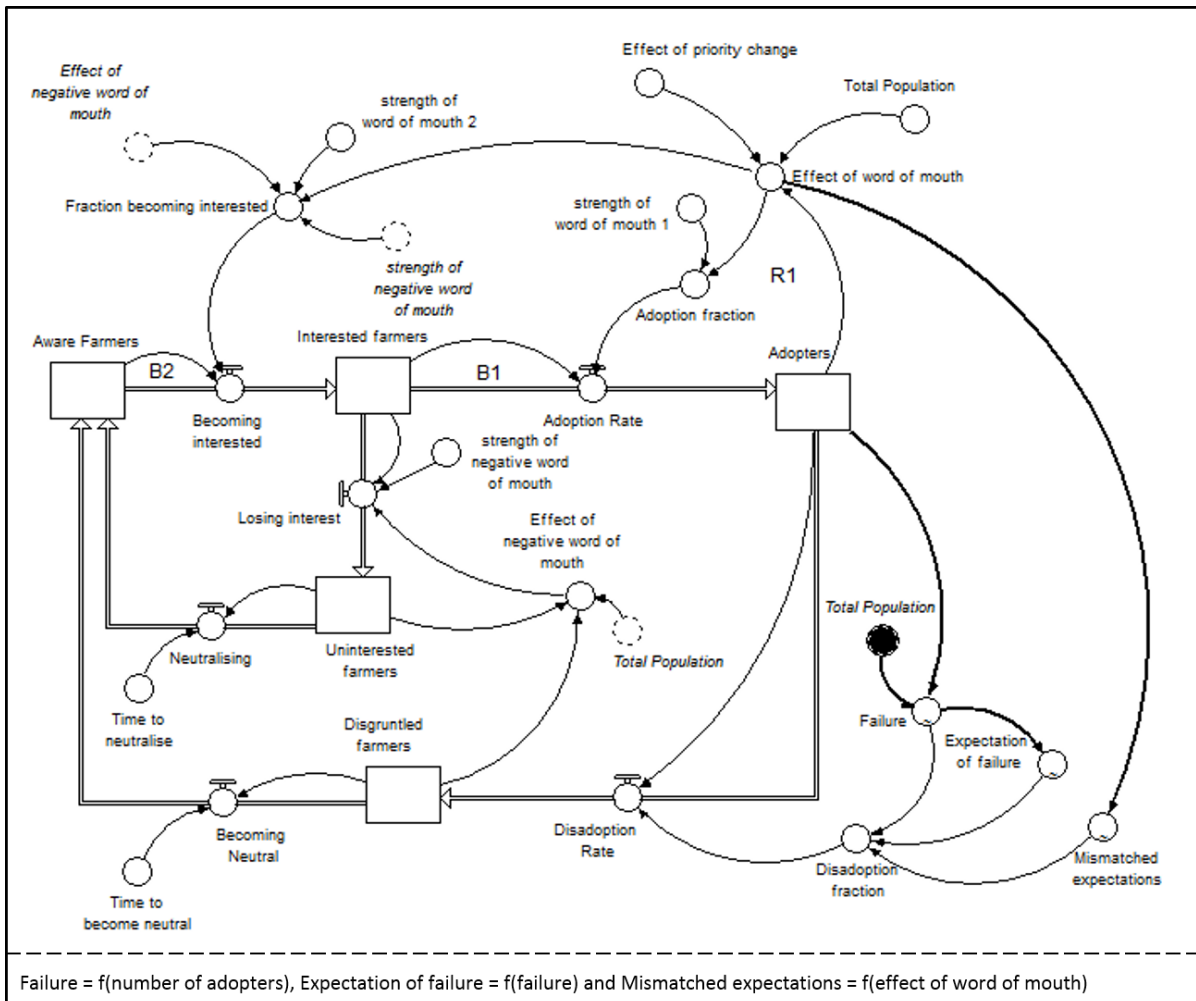


Figure 5.16 Illustrating the causal variables that inform “failure”, “expectation of failure” and “mismatched expectations”

The graphical input function for “mismatched expectations” is shown in Figure 5.17. As illustrated, “mismatched expectations” was configured to be dependent on the “effect of (positive) word of mouth”. Intuitive logic suggests that when the existing number of “adopters” in the real world was low, positive word of mouth will also be weaker, resulting in poor knowledge of the innovation and its capabilities amongst the non-adopter farmers in the community. The potential for mismatching of expectations is higher. As word of mouth increases, farmers will learn from the experiences of other farmers and develop a more informed opinion and expectation of the innovation. The assumed (positive) “word of mouth” and “mismatched expectation” relationship is depicted in Figure 5.17. The strength of the “mismatched expectation” variable weakens as positive “word of mouth” grows, eventually reaching zero when 40% of the total population become “adopters”. The explicit assumption was that when 40% of the population become “adopters”, positive “word of mouth” would be

strong enough to eliminate all opportunities for “mismatched expectations” to arise. The merit of the assumption, in the absence of data, is further discussed in Section 5.4, page 92.

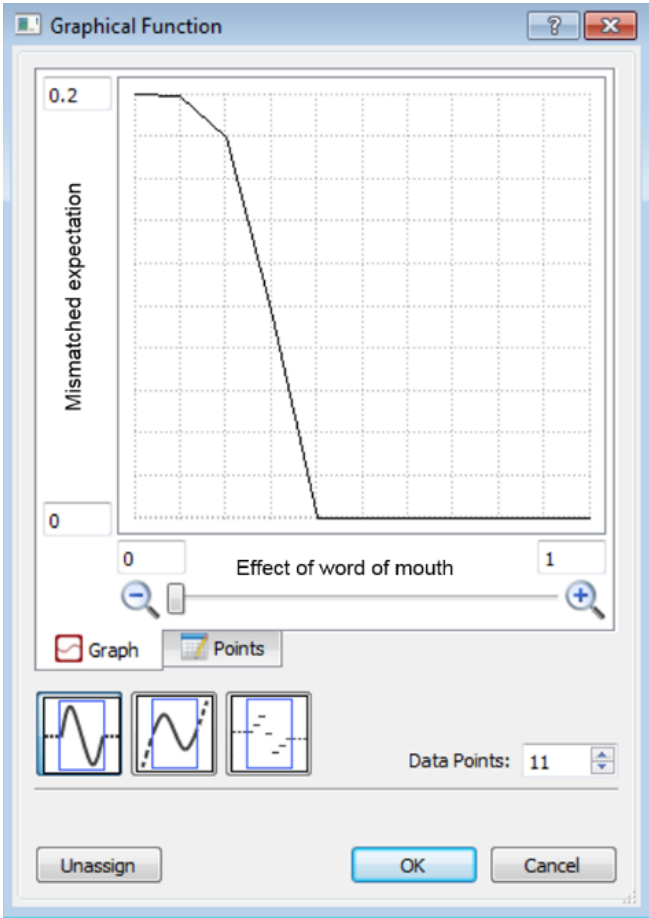


Figure 5.17 Causal relationship for “mismatched expectations”

Furthermore, dis-adoption in the initial phases is driven by the “failure”, “expectation of failure” and “mismatched expectations” variable. Once dis-adoption has been triggered to stimulate “negative word of mouth”, the “negative word of mouth” variable can also feedback to further strengthen the “dis-adoption fraction”. As shown in Figure 5.18, the “dis-adoption fraction” is now a function of “failure”, “expectation of failure”, “mismatched expectations”, plus the “effect of negative word of mouth” multiplied by the “strength of negative word of mouth”.

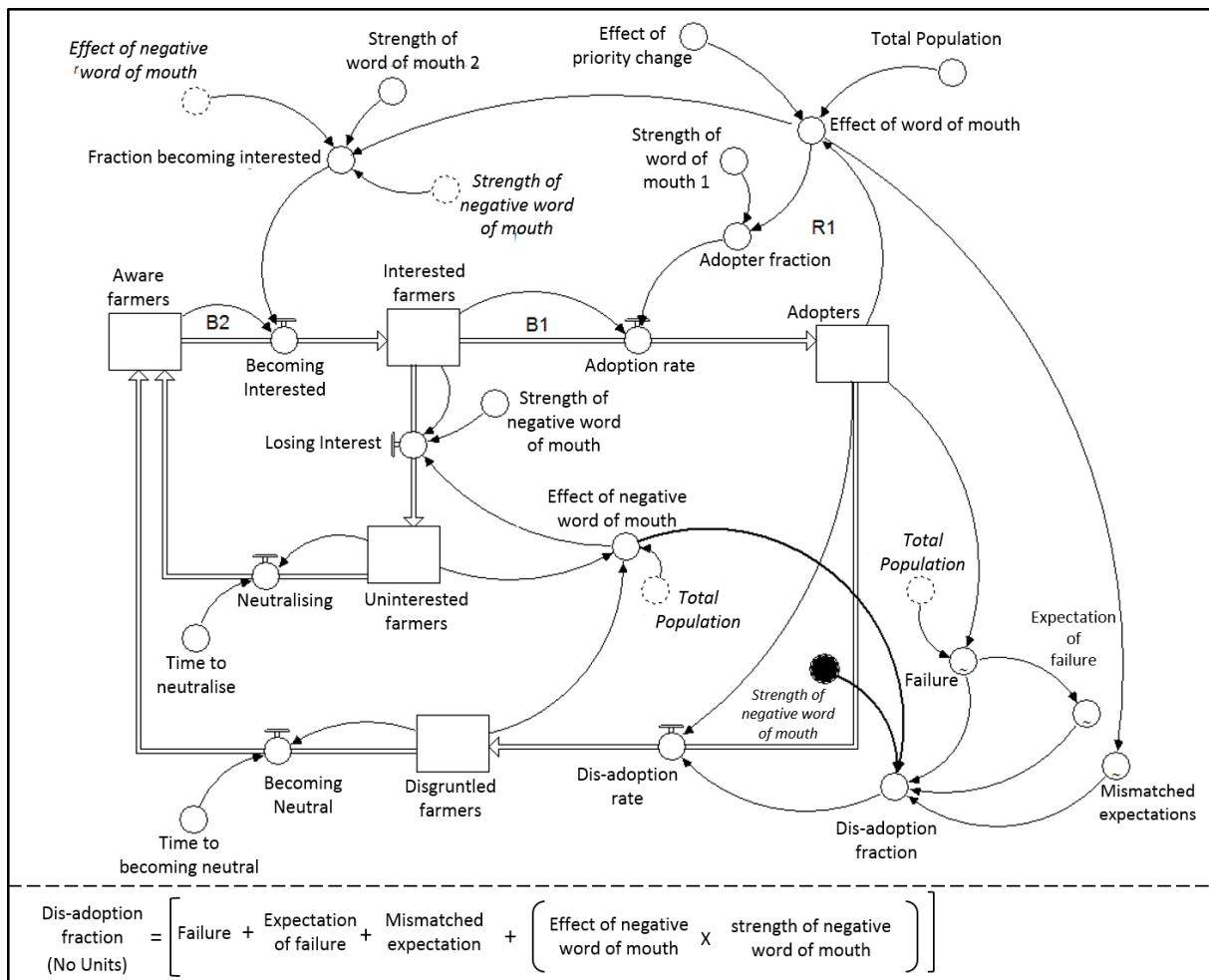


Figure 5.18 Effect of “negative word of mouth” feeding back to contribute to dis-adoption

The final element in the model was the role and influence of extension support to minimise dis-adoption. The narrative data clearly indicated that when extension specialists play the role of a sounding board, they help, to some extent, to reduce the uncertainty and potential for dis-adoption. This causal force is depicted in a simplified manner as shown in Figure 5.19.

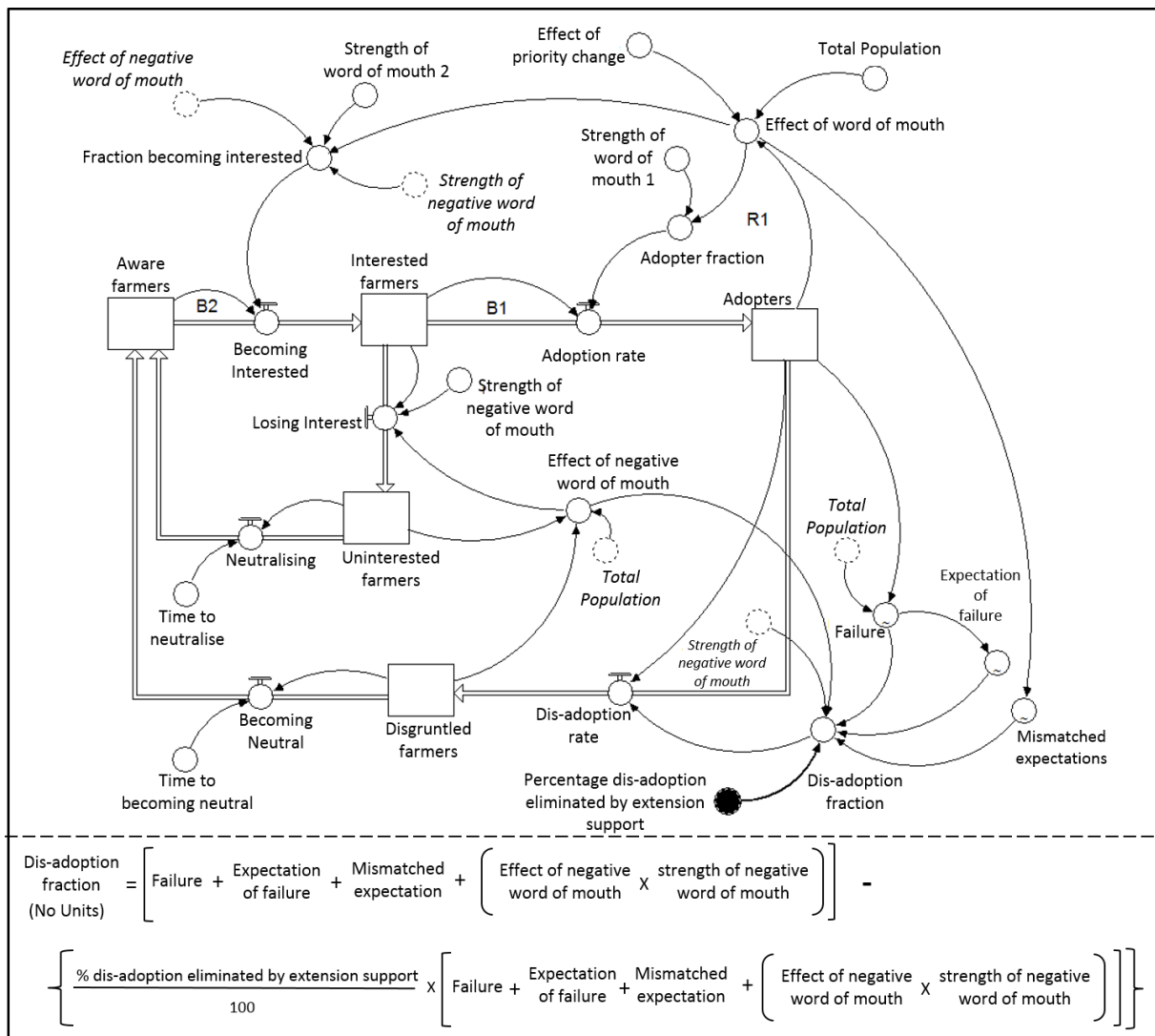


Figure 5.19 Introducing extension support to eliminate a portion of failure

The variable “percentage dis-adoption eliminated by extension support” is a switch which can be set at any value between zero and a hundred. The higher setting corresponds to more effective extension support and a lower dis-adoption fraction. The extension support variable serves as a lever, which can be used to generate several scenarios in modelling experiments.

This completes the mapping of the underlying system structure. The stock flow map depicts, transparently, the set of dynamic causal relationships and interdependencies which give rise to the behaviour modes of the system. In summary, growers progress in stages across the stock flow chain. The first stage is when a grower first becomes aware of the innovation. The second stage is when a growers becomes interested in the innovation. In formulating an opinion, a grower will start to research the product and learn more from peers (word of mouth). When the grower is satisfied with the product and what he has learnt about it, the next stage is adoption.

Adoption can follow on to become dis-adoption, initially driven by “failure”, “expectation of failure” and/or “mismatched expectations”. Dis-adoption can result in “negative word of mouth”. “Negative word of mouth” can result in non-adoption, when “interested farmers” “lose interest” to become “uninterested farmers”. “Uninterested farmers” can further reinforce “negative word of mouth”. “Negative word of mouth”, once stimulated via disgruntled dis-adopters can feedback to further contribute to dis-adoption.

The model structure and software simulation capability collectively offers a view of the life cycle of the adoption process across a community. This includes the initial introduction of an innovation into the farming community and the range of possible outcomes, such as non-adoption, successful adoption, or initial adoption followed by varied degrees of dis-adoption and non-adoption in the end.

To help the reader cope with the complex and messy stock flow diagram in Figure 5.19, a schematic of the main causal forces in the system dynamics model is presented in Figure 5.20. The figure makes it easy to understand that positive word of mouth, on the left hand side of the scale works in the opposing direction to dis-adoption and negative word of mouth, on the right hand side of the scale. All forces are dependent on the existing number of “adopters” in some way. The outcome, in terms of adoption success or failure, is dependent on which side of the scale tips with the stronger influence.

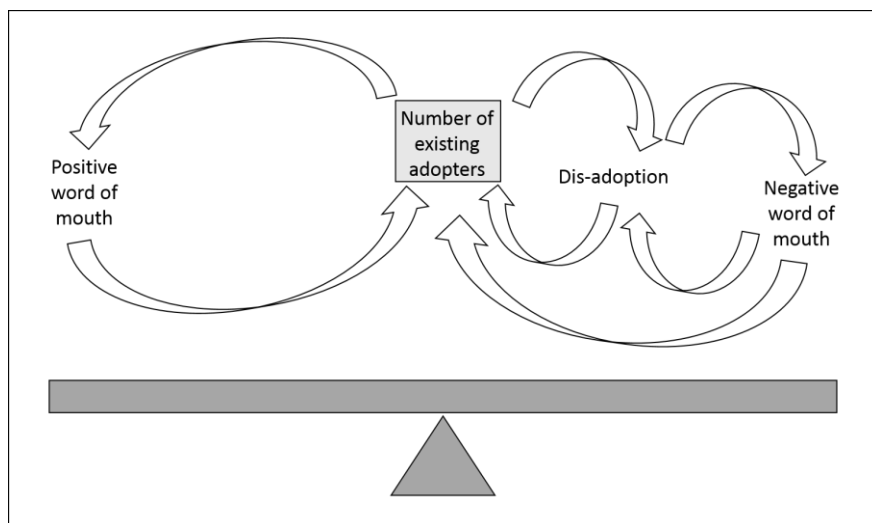


Figure 5.20 Summary of causal forces in the word of mouth model

5.3 Model Simulation and Testing (Word of Mouth Model)

In this section, various scenarios are simulated in order to create opportunities for reflection and learning about the operational realities of the complex system and its causal structure. Before conducting any simulation, certain model variables must be configured with reasonable default or representative initial condition values. The opportunity for learning, debate and alignment of mental models becomes available when these assumptions are made visible to the model audience. Over and above setting the initial conditions and default values, the model user must also take cognisance of certain variables which can function like levers which control or influence the behaviour of the system. These levers are used for model testing and experimental learning. Essentially, different lever settings correspond to different real world circumstances. Hence, model behaviour for a specific lever setting can be compared to the expected or observed behaviour mode in the real world for the corresponding real world context. Flaws in the computer model and/or mental models are usually detected when the simulated and expected real world behaviour patterns do not match each other (Sterman, 2006). The variables and corresponding initial condition or default values are reported on Table 5.1.

Table 5.1 Initial condition, default values and the variable range for selected model variables

No	Variable (stocks)	Initial Condition	Range
1	Aware Farmers	80	0 – 100
2	Interested Farmers	15	0 – 100
3	Adopters	5	0 – 100
4	Disgruntled Farmers	0	0 – 100
5	Uninterested Farmers	0	0 – 100
No	Variable (Parameters)	Default Value	Range
1	Strength of word of mouth 1	0.3	0 – 1
2	Strength of word of mouth 2	0.5	0 – 1
3	Strength of negative word of mouth	0.5	0 – 1
No	Variable (Levers)	Default Value	Range
1	Effect of priority change	0	0 – 100
2	Percentage of dis-adoption eliminated by extension support	0	0 – 100

As indicated in Table 5.1, only two model variables are available as levers which could be used to stimulate a change in the system behaviour. The variables are “effect of priority change” and “percentage dis-adoption eliminated by extension support”. In order to test, learn from and develop a greater appreciation of the model’s causal structure, the scenarios depicted in Table 5.2 were run (with all other variables set as the default value).

Table 5.2 Summary of simulation inputs/scenarios

Scenario Number	“Effect of priority change” (value)	“Percentage dis-adoption eliminated by extension support”
Category 1		
1 (baseline)	0	0
2	50	0
3	100	0
Category 2		
4	0	90
5	0	92
6	0	95
Category 3		
7	100	50
8	100	79
9	100	80
10	100	95

As shown Table 5.2, the scenarios can be lumped into 3 categories. In the first category, only the “effect of priority” variable was varied. Extension support was non-existent in this set of scenarios. In the case study area, due to the perceived high costs, farmers opted to not subscribe for extension services for a period of 8 years (1991 – 1993 & 2005 - 2009). Hence this category where no extension was available to help reduce dis-adoption is realistic. In addition, fluctuating levels of water availability and the associated costs of constructing of a large new dam in the catchment were real world factors which were present and likely to increase the priority of water in the minds of farmers.

In the second category in Table 5.2, the “effect of priority change” is held at zero, while the variable “percentage of dis-adoption eliminated by extension support” is varied. Over and above allowing the reader to view the sensitivity of model behaviour to the input variables, this category, also resonated with real world occurrences. As time moved along, farmers reversed their decision and opted to subscribe and pay for extension services again. The dam construction was complete, and water supply and costs stabilised, unfortunately resulting in the priority of water management dropping again.

In the last category, the “effect of priority” is held at 100 (the maximum value), while the “percentage of dis-adoption eliminated by extension” is varied. Once again this category resonates with the real world. The current rapid rise in electricity tariffs continues to steer farmers towards the importance of water management and irrigation scheduling. From the exploratory interviews, many farmers reported that electricity is now in line with labour as the highest input costs (data not presented). It was concluded that the priority of water management was perhaps at an all-time high. To exaggerate the situation, and to test the model at the extreme, the “effect of priority” variable was held constant at the highest value, 100. In addition, extension was now well established in the area. Extension specialists, however, were required to focus on an array of topics/disciplines. This implied that extension’s availability to eliminate dis-adoption of irrigation scheduling innovations may have been varied and inconsistent. The model was, therefore, used to simulate behaviour at different levels of extension support.

The results of the simulations, grouped into the above mentioned categories, are presented in Figure 5.21, 5.22 and 5.23. The simulations results shown, depict the levels of the different stocks (in the units number of farmers) over a period of 100 years. It is also necessary to ensure that the stock flow diagram, shown in Figure 5.19, is used to analyse and interpret the simulation results. The reader should preferably have a printed copy of Figure 5.19 available on a separate leaflet when studying the simulation results. A larger printer friendly version of the model map is provided in Appendix 1.

The results for simulation category 1, shown in Figure 5.21, were relatively uneventful. Activating the “effect of a priority” change did not influence any substantial changes in the behaviour modes of the stocks. At the beginning of the simulation (time = 0 years), there were initially 5 “adopters”. These 5 “adopters” generate a weak “word of mouth effect”, which causes only a few farmers to leave the “aware farmers” stock and become interested. This is visible by

the initial small drop in the “aware farmers” stock in the first year and the consequent small increase in the “interested farmers” stock. Note, in Figure 5.19, the “aware farmers” can only flow into the “interested farmers” stock. Hence a decrease in one stock must necessarily result in an increase in the next stock.

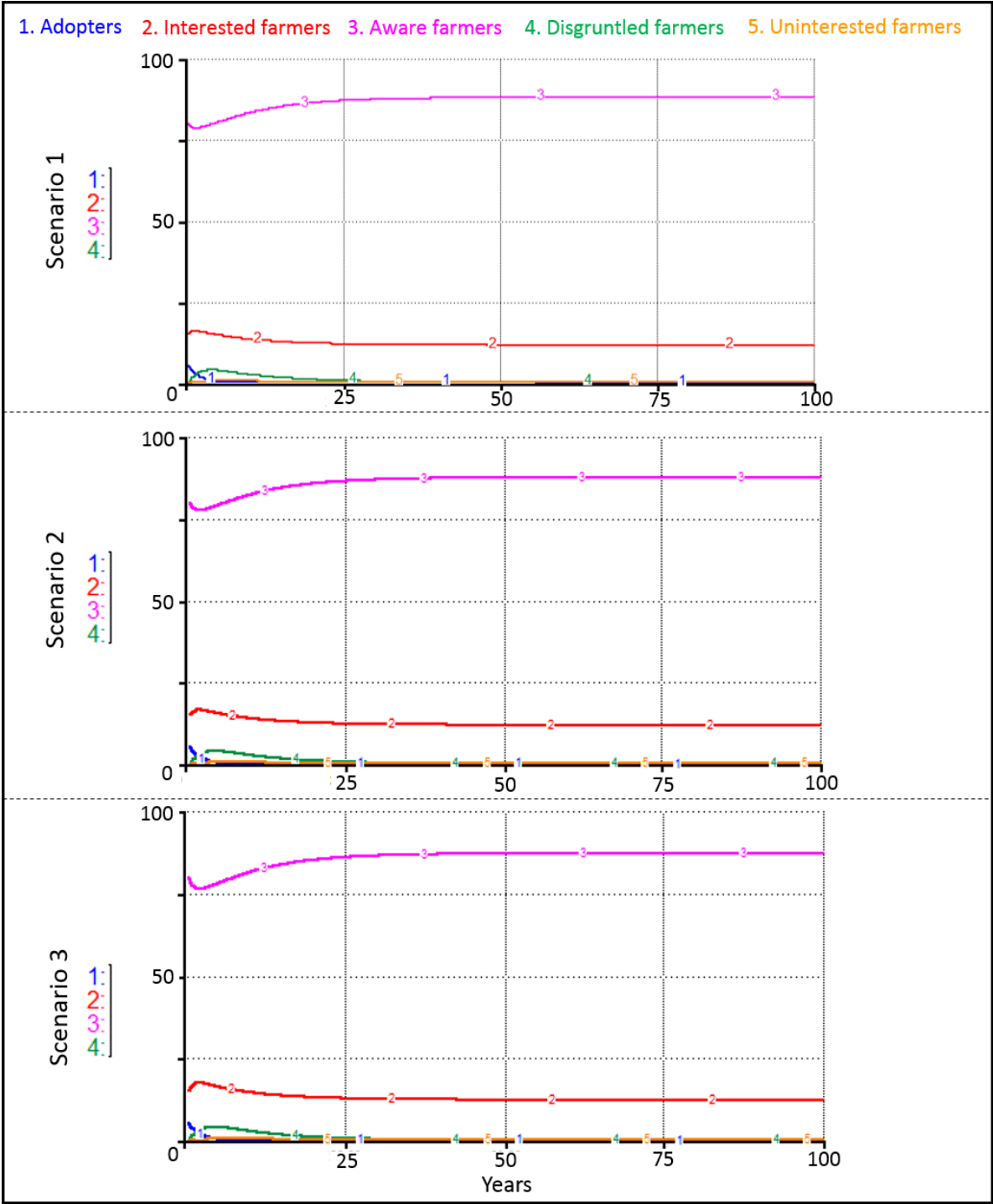


Figure 5.21 Simulation results associated with a priority change only (Category 1: Table 5.2)

Furthermore, in these scenarios, there was no extension support to reduce dis-adoption. Hence, the initial 5 “adopters” quickly dis-adopted. The adoption curve, in Figure 5.21, drops from the initial 5 farmers to 0 in the first 5 years, corresponding to an increase in the number of “disgruntled farmers” in the same time segment. According to the stock flow diagram, the presence of “disgruntled farmers” will trigger the “effect of negative word of mouth”. Hence, corresponding to the presence of “disgruntled farmers” (and negative word of mouth) in the first 20 years, the number of “interested farmers”, after the initial small increase, also shows a decline in Figure 5.21. Interestingly, the outflow from the “interested farmers” stock to the “uninterested farmers” stock is not reflected in Figure 5.21, i.e. no apparent increase is visible for the “uninterested farmer” curve for the same time segment. This is because the small inflow into the “uninterested farmer” stock was matched by the “neutralising” outflow. The effect of “becoming neutral” and “neutralising” explain the gradual reduction in the “disgruntled farmers” stock, and the increase in the “aware farmers” stock after the initial drop, respectively (Figure 5.21).

After year 20, the “aware and interested farmers” stock reaches an equilibrium state of 87 and 13 farmers, respectively. A state of equilibrium indicates that there are either no inflows or outflows from the stock, or that the inflow and outflows are balanced (net flow = 0). In this case, there were no flows in the system. Since the “adopter”, “disgruntled farmers” and “uninterested farmers” stocks are 0, there is neither positive nor negative word of mouth in the system. The first set of simulation results, highlight a few key lessons to take away from this model. The first is the inherent connectivity which exists between the different stocks. Even a small change in any stock, will by virtue of its connectivity, propagate some impact on the rest of the system. Secondly, the distribution of the population amongst the various stocks is key in terms of activating and deactivating the positive and negative word of mouth feedback loops. These ideas will be further built upon when analysing the next set of simulation results. Finally, this uneventful set of simulation results confirms that the model relies on dis-adoption and the positive and negative word of mouth feedback loops to derive system behaviour. When there was no dis-adoption and word of mouth (positive or negative) in the system, all stock behaviour stabilised. In an abstract manner, the model allows one to understand the cause and effects of dis-adoption and the “effect of word of mouth”, without the contaminating effect of other variables. While this is a good thing, it also confirms that this model on its own is perhaps not enough to fully explain the dynamics of adoption. The literature and narrative data presented in Chapter 4, suggested that word of mouth was effective for the majority of the population, but

learning and experiencing was important for the early adopters. Early adopters are required to initiate the positive word of mouth feedback loop. This alludes to the reason for constructing the second system dynamics model. More about this in Chapter 6.

In the next set of simulation results, in Figure 5.22, the “effect of priority change” was maintained at 0, while the “percentage dis-adoption eliminated by extension support” was set at 90, 92 and 95 for scenarios 4, 5 and 6, respectively. It is important to remind the reader, that the absolute values of both the input variables and simulation results are less important in comparison to the behaviour modes and direction of causal influence. The model is designed to serve as a learning tool to better understand the dynamic complexity of interactions as they might occur in the real world. Hence, derivation or prediction of exact timelines for adoption, etc. was considered less important. In the same light, the input values of 90, 92 and 95 for the variable “percentage dis-adoption eliminated by extension support” was purposefully selected. They do not necessarily reflect the absolute values of percentage dis-adoption which extension must strive to eliminate. Instead, they represent the region where the model’s outputs were most sensitive to this input variable. As stated before, the aim was to use the model as a learning tool.

The adoption curve for scenarios 4, 5 and 6 (Figure 5.22) were substantially different for only small changes in the input variable (“percentage dis-adoption eliminated by extension”). In scenario 4, the adoption curve does not reach equilibrium. The stock of “adopters”, however, never rises or falls much more than the initial 5 farmers. Adoption never takes off! The relative flatness of the “adopter” curve indicates that the inflow is well matched to the outflow, i.e. adoption via positive word of mouth is being cancelled out by dis-adoption. It is plausible that initially a few farmers, due to “failure”, for example, decide to dis-adopt and go on to spread negative word of mouth, while the remaining adopters continue to inject positive word of mouth into the system simultaneously generating interest and adoption. The visible (but small) increase in the number of “disgruntled farmers” indicates an outflow from the “adopter” stock, via dis-adoption, and the triggering of the negative word of mouth feedback loop. The slight increase in the number of “uninterested farmers” confirms the “effect of negative word of mouth”. In the presence of an outflow, the “adopter” stock can only maintain a flat curve, if an inflow similar in quantity to the outflow exists. Hence, positive word of mouth from the remaining adopters, together with the help of extension to eliminate 90% of dis-adoption, can have the effect of cancelling out dis-adoption and negative word of mouth. Unfortunately, in this scenario, it is still not enough to help adoption take off.

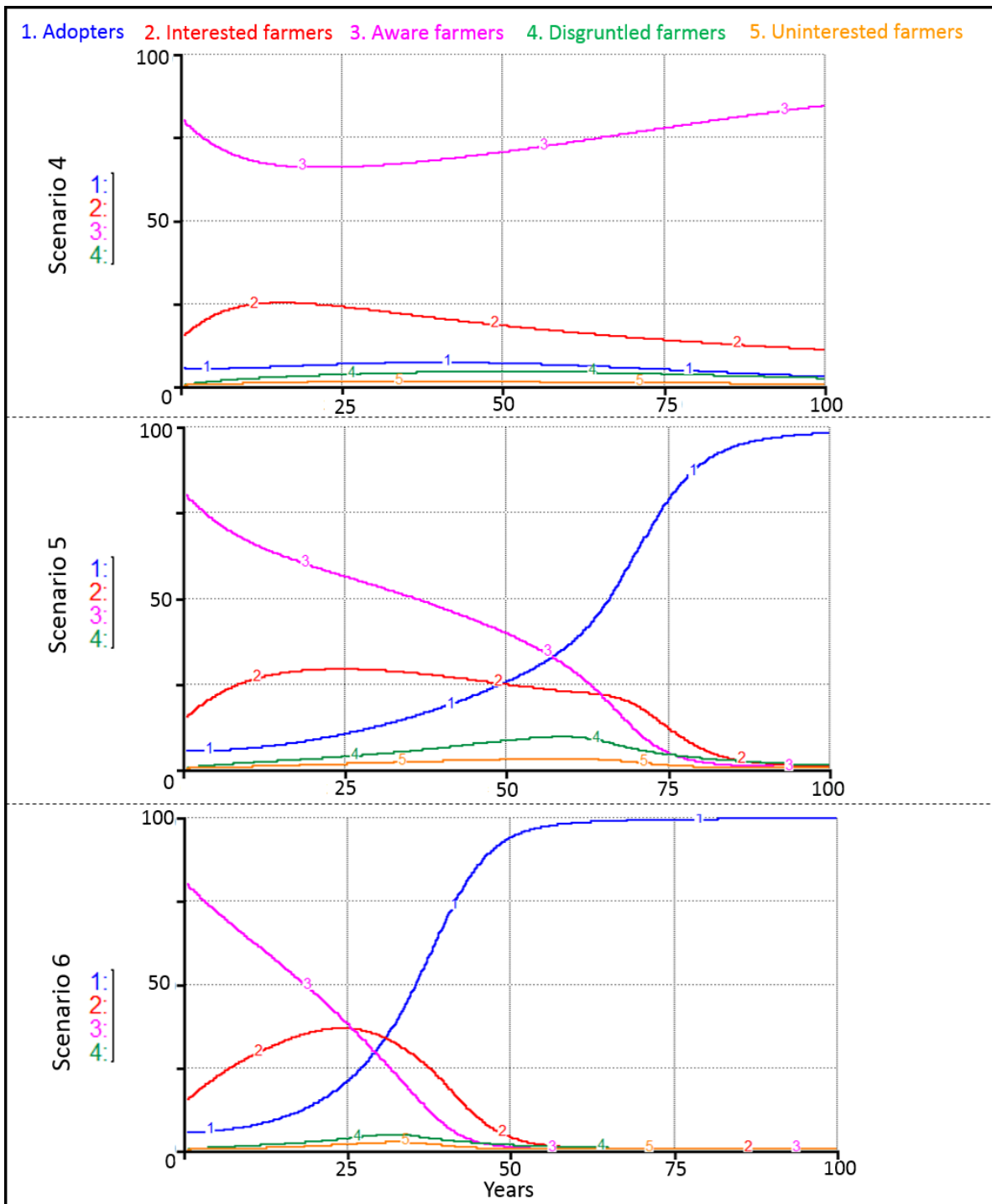


Figure 5.22 Simulation results when selected percentage of failure was eliminated by extension support (Category 2: Table 5.2)

In scenario 5 (Table 5.2), the “percentage of dis-adoption eliminated by extension support” was only increased by 2 units (90 in scenario 4 to 92 in scenario 5). This small change in the input variable brought about a big change in the model output. The “adopter” stock now exhibited

continuous growth over the simulation period. In addition the growth of the “adopter” stock was nonlinear, i.e. the slope of the curve was different at different time segments. In essence, the accumulating (snowballing) effect of the positive word of mouth loop was being depicted. The small increase in extension support had the effect of tipping the scale, such that the positive word of mouth feedback loop gradually became more dominant than dis-adoption and the negative word of mouth feedback loop. This is not to say that there was no dis-adoption and negative word of mouth effect. In scenario 5, the “disgruntled farmers” curve and the “uninterested farmers” curve visibly increase to slightly higher numbers than for scenario 4. This implies that dis-adoption and the “effect of negative word of mouth” was slightly higher in scenario 5 than for scenario 4, despite slightly more extension support.

The first lesson to take away from this point is the deceptive nature of complex systems and the difficulty to project outcomes if data is only drawn from a limited/confined portion of the system. In the real world, if an extension specialist was only exposed to signals from the “disgruntled” and “uninterested farmers”, and the signals (in the form of negative word of mouth and increasing number of “disgruntled farmers”) were getting louder, the extension specialist may very well be tempted to reduce or stop his support for an innovation, wrongfully believing that the innovation will not be adopted by the larger community.

The second lesson is related to the non-linear growth of the adoption curve. Despite the extension effort remaining consistent throughout the duration of the simulation, the “adoption rates” change dramatically. Initially, the growth of the “adopter” stock is slow. Beginning at 5 “adopters” in year 0, the total number of “adopters” increases to 10 after year 25. All other variables being held constant, including the extension support, the number of “adopters” increases to 25 in the next 25 years. In the 3rd quarter, the “adopter” stock grows dramatically to 78 farmers in year 75. In the last 25 years, the effects of the saturation balancing feedback loops slows down the growth of the “adopter” stock. The “adopter” stock ends with the value of 98 farmers after the 100 year simulation period. Remember the model has not been calibrated to be predictive, hence the reader is encouraged not to pay attention to the unrealistic timelines. Instead, pay attention to the shape of the “adopter” curve, especially the dramatic growth in the 3rd quarter of the simulation period. The turning point on the “adopter” curve coincides with a value of 35 “adopters” (in year 59). The value of 35 “adopters” represents a critical mass necessary to intensify the positive word of mouth feedback loop for aggressive growth. When the critical mass is attained, an additional 58% of the farmers become adopters in just 21% of

the time. The principle of a compound growth curve is that large growth takes place in a short space of time when the turning point (in this case, the critical mass of “adopter” farmers) is attained. The implication is that in the real world, extension specialists may have to work hard supporting innovations for longer periods of time, realising very little visible results initially, with the understanding that rapid adoption will only take place once a critical mass was available to adequately intensify positive word of mouth.

In scenario 6, the “percentage dis-adoption eliminated by extension support” is increased to 95 %. The result shown in Figure 5.22 depicts the enhanced dominance of positive word of mouth over dis-adoption and negative word of mouth resulting in faster and sustained adoption. The increased extension support never allows dis-adoption and negative word of mouth feedback loop to get off the ground.

The results for scenario 6 indicate that all farmers eventually adopt. In the real world, a 100 % adoption is an unlikely outcome. Such a flawed simulation result, however, can be useful in stimulating debate about what the acceptable levels of adoption are in a farming community. If not a 100%, what percentage of the farming community can be expected to adopt?

Furthermore, all curves reach equilibrium just after 50 years. This is because the system reaches the saturation point. At this stage, all farmers are in the “adopter” stock. Hence, there are no more potential adopters in the system. Even though positive word of mouth may be strong as a causal force, there are no individuals for it to act on. Secondly, since there are also no “disgruntled and uninterested farmers”, there is no negative word of mouth. Thirdly, a 100 % of the farming population in the adopter stock also means that “failure”, “expectation of failure” and “mismatched expectations” are eliminated along with dis-adoption. All causal forces, summarized in Figure 5.20 become nullified at the saturation stage.

In scenario 6, the “aware farmers” curve displays a continuous decline, suggesting that inflows from becoming neutral and neutralising were negligibly small, while outflows into the “interested farmers” stock was bigger. Similarly, the “interested farmers” stock exhibited a net increase initially and a net decrease later. The initial net increase indicates that the inflow of “aware farmers” into the “interested farmers” stock was initially larger than the outflows into the “adopter” and “uninterested farmers” stocks. After year 25, however, the outflow increases substantially (most likely dominated by aggressive adoption) resulting in a net decrease in the

“interested farmers” stock until there are no more “interested farmers” in the system. In the real world, it might be relatively easy and therefore tempting for the extension specialist to keep track of the number of “interested farmers”. Perhaps it is important to make note that the “interested farmers” stock is not necessarily a good proxy which extension specialists can use to project future adoption levels or likelihood of adoption success. In scenario 6, the “interested farmers” stock increases and decreases at different time segments, while the “adoption stock” was increasing throughout the duration of the simulation.

The results for scenarios 7, 8, 9 and 10 are presented in Figure 5.23. In this set of scenarios, the “effect of priority change” variable was held at the maximum, while the “percentage dis-adoption eliminated by extension” variable was set at 50, 79, 80 and 95, respectively. To remind the reader, when the “priority change” variable is set to 100, the “effect of word of mouth” is doubled. This was representative of the real world situation where the rapid increases in electricity tariffs were increasing the importance of irrigation management. Hence, farmers were considered to be more receptive to the “effect of positive word of mouth” about irrigation scheduling. The varying levels of extension support account for the possibility that extension specialist also have to deal with other disciplines such as pest and diseases, varieties, soil health, etc. Hence, the time and energy available to support irrigation scheduling innovations can be varied.

Scenario 7 and 8 depicts adoption failure modes, while scenario 9 and 10 depicts adoption success modes. Scenario 7 resulted in complete adoption failure while scenario 8 depicts an initial gradual increase in adoption followed by a gradually decline to 0. Scenario 9 depicted a more gradual increase in the “adopter” farmers, while scenario 10 displayed the most rapid response.

As was the case in Scenario 5, despite increasing extension support in scenario 8 and 9, the “disgruntled farmers” stock also increased to higher levels than for scenario 7. Once again this is evidence of the complex dynamic and interconnected nature of systems behaviour. Intuitive attempts to predict behaviour can be flawed. Because the “percentage dis-adoption eliminated by extension support” was increased, this does not necessarily result in reduced dis-adoption. Counterintuitively, the simulation results for scenario 8 and 9 reveal exactly the opposite. The increase in extension support resulted in an increased number of “disgruntled farmers”.

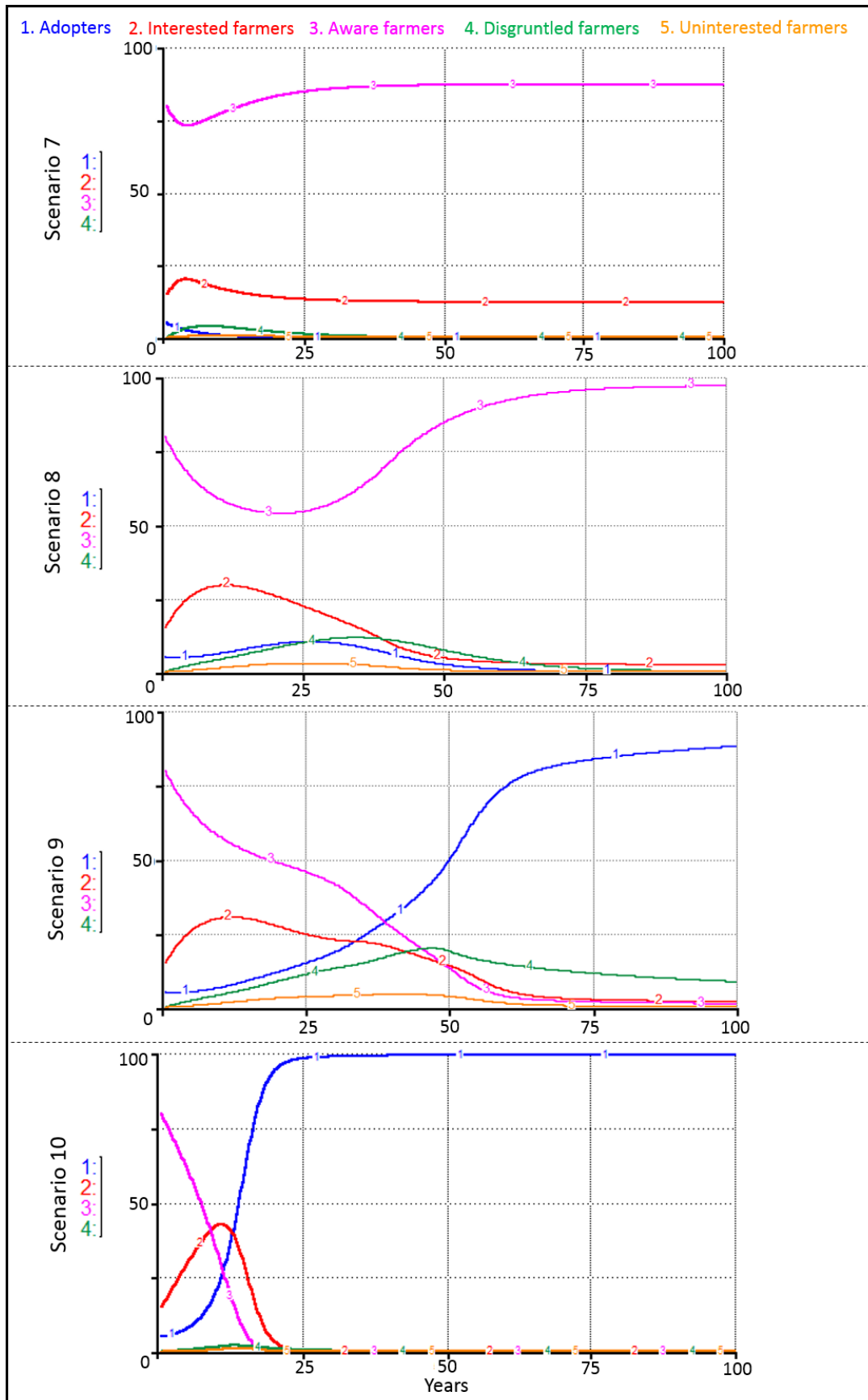


Figure 5.23 Simulation results for maximum priority and varied levels of eliminating dis-adoption (Category 3: Table 5.2)

The systemic structural relation between the number of “adopters” and the “disgruntled farmers”, programmed into the system dynamics model, helps to explain the counterintuitive behaviour. In scenario 8, the extension support helps to limit the initial 5 adopters from dis-adopting. This helps to trigger the positive word of mouth feedback loop, which in turn increases the number of adopters. The “dis-adoption rate”, however, is also a function of the number of adopters (Figure 5.10). In the model, the “dis-adoption rate” was mathematically defined as the number of “adopters” multiplied by a “dis-adoption fraction” (i.e. a fraction of adopters become disgruntled dis-adopters every year). Hence, the increase in “adopters” mathematically overrides the presence of extension support at the specific variable setting for scenario 8, to also bring about an increase in the number of “disgruntled farmers” (via dis-adoption). Visibly, the convergence of the “adopter” and “disgruntled farmers” curves in scenario 8 is an indication of the impending adoption failure. In other words, the absolute values of the “adopters” and “disgruntled farmers” stocks are less important in comparison to the relative difference between the two stocks.

Furthermore, the difference between adoption success and failure in scenario 8 and 9 was attributed to increasing the “percentage of dis-adoption eliminated by extension support” by just 1 unit. The important thing to highlight here is the innate difficulty the human brain has in trying to explain or predict such tipping point behaviour via mental simulation. The dynamic circular causality embedded in the structure of the system is difficult to decipher. Estimating the strength of “positive word of mouth” and the resultant “adoption rate” as a function of the number of existing “adopters” may be relatively easier. But trying to estimate the “dis-adoption rate” is more difficult. Firstly, as discussed above, an increase in the number of “adopters” can increase the “dis-adoption rate”. But a higher cognitive effort is required to remember that the increase in the “dis-adoption rate”, as a result of increased “adopters”, introduces an opposing force (i.e. a drainage flow from the “adopter” stock). The inverse relationship requires more thinking effort to comprehend the dynamics. For example, “failure” is high when the number of “adopters” is low, and “failure” is low or zero when the number of “adopters” is high. In other words, a high value with respect to the “failure” variable is a bad thing, while a low number with respect to the number of “adopters” is also a bad thing. High and low values are ‘good or bad’ things depending on how they connect to the system and the relative state of the system at that point in time.

In addition, the “dis-adoption fraction” is difficult to estimate, mentally. The “dis-adoption fraction” is dependent on variables such as “failure”, “expectation of failure”, “mismatched expectations” and “negative word of mouth”, all of which are dynamic, non-linear and interconnected to the system. Dynamic and interconnected refers to the fact that the current state of the system informs the strength of the variable, which in turns influences a change in the state of the system. The brain first has to detect the state of the system, then use that information to estimate the strength and causal direction of the individual variables, and finally predict the degree of change that will be influenced on the system by the collective action of all the variables in the next time step. Cognitive capabilities to simultaneously compute a number of variables and estimate the collective effect, mentally, is virtually impossible (Sterman, 1994). Non-linear refers to the fact that the strength or value of the variables “failure”, “expectation of failure”, “mismatched expectations” and “negative word of mouth” are neither consistently the same, nor incremental in the way they might change from one time step to another. This is easier to appreciate when viewing the results for scenario 10.

In scenario 10, 95 % of dis-adoption is eliminated by extension support. The presence of dis-adoption is virtually negligible, making it relatively easier to predict and explain the results. The existing adopters immediately trigger the “effect of word of mouth”, in an amplified manner since the priority variable was set at 100. The “effect of word of mouth” stimulates both the “becoming interested” and “adoption rate” flows. Since the drainage flow from “adopters”, namely “dis-adoption rate”, was negligible, the number of “adopters” continues to increase, further increasing the “effect of word of mouth”, until saturation is reached.

5.4 Flaws and Weaknesses in the Word of Mouth Model

The famous quote, “all models are wrong, but some are useful” (Box, 1976), forms the premise for this section. It would be unrealistic for a reader to expect a perfect model. The author wishes to acknowledge that the system dynamics models presented in this document are far from perfect and due consideration is necessary for future application of the model and/or use of the simulation outputs reported in this document. This section does not provide a comprehensive account of the model flaws and weaknesses. Instead, the aim is to sensitise the reader in order to limit misinterpretation and misuse of the model map and simulation outcomes.

The main weakness in the word of mouth of model revolves around the numeric estimation of parameters and relationships, for which there is no real world data, or no easy way to collect such data from the real world. The “strength of word of mouth” and “time to become neutral” variables are examples of such parameters in the word of mouth model. The word of mouth success rate for generating interest and/or influencing peers to adopt is expected to be dependent on many factors. The individual’s social status, past farm performance (reputation), communication skills, contact time with peers, for example, could all easily influence the strength of positive or negative word of mouth. Hence, the “strength of word of mouth” can differ from one individual to the next. Collecting data to estimate the “strength of word of mouth” in the real world is a difficult task. The same is likely to be true for the “time to neutralise” variable. Each individual, based on their characteristic traits, social support and context is likely to have different time spans for forgetting bad past experiences with innovations before they become available to consider a new innovation. Similarly, mathematically codifying of the “failure”, “expectation of failure” and “mismatched expectations” variables are also examples of relationships which were difficult to quantify. The non-linear graphical relationship was developed to represent the dynamic nature of the variable in a simplified and intuitive manner without any supporting evidence from the real world. Despite the lack of real world data, system dynamic experts suggest that it is better to represent a causal variable in a simplified and transparent manner, as opposed to omitting the variable due to lack of data (Sterman, 1994). Transparent representation allows for robust scrutiny, debate and surfacing of research gaps.

The next aspect relates to model comprehensiveness and model boundaries. The aim of a system dynamics model is usually not to model the world. Hence, the author acknowledges that there are number of variables which could have been, but were purposefully not included. For example, mapping and modelling of the dis-adoption fraction was not comprehensive, nor scientifically rigorous in this study. An assumption was made that farmers dis-adopting due to “failure” will not be more than 20% of the existing “adopters”. This assumption can easily be contested. The occurrence of such a failure event in a unit of time will likely coincide with the specific alignment of a number of causal factors. The model could easily have been expanded to detail the various variables which cause failure. For example, skill, exposure to training, knowledge, commitment and dedication can possibly feature as variables in modelling the “failure” variable. Expanding the model boundary in this direction, however, would have drifted from the main goal. Instead of modelling the whole world, one aims to model a specific

problem (Richardson, 2011). The result, as suggested by the experts (Richardson, 2011), was to use the bare minimum number of variables/model structure capable of exhibiting the problematic behaviour. Hence, while simplified assumptions were used, care was taken to ensure that the model structure can allow for generating and studying the problematic behaviour, poor adoption in this instance.

5.5 Summary and Discussion

Despite the limitations highlighted in the previous section, the model and simulation experiments offered opportunities for learning and reflection. The important role of extension support, as highlighted by the narrative data from the extension specialists themselves, was confirmed in the simulation results. A case in point was the complete adoption failure in scenarios 1, 2 and 3, when no extension support was activated, even in the presence of amplified word of mouth when the priority for irrigation management variable was set at the maximum.

In the system dynamics model, extension support was causally linked to eliminating a proportion of dis-adoption. Dis-adoption in turn was linked to the number of existing adopters, and interestingly, the number of adopters was also the driver for positive word of mouth. Hence, as shown in Figure 5.20, the number of adopters is a central variable in determining the balance of forces and the resultant adoption success or failure in a farming community.

Of particular interest is the dynamics in the initial stages when the number of adopters in the community is low. Figure 5.24 displays a simplified schematic of the balance of forces in the system, as a function of the underlying structure and innate mathematical formulation. When the number of “adopters” is low, positive “word of mouth” is weak. Simultaneously, “failure”, “expectation of failure” and “mismatched expectations” are strong, resulting in stronger dis-adoption (tipping the scale towards dis-adoption). Stronger dis-adoption leads to “negative word of mouth” which makes dis-adoption even stronger. “Negative word of mouth” also inhibits the flow into the “adopter” stock by stimulating “interested farmers” to “lose interest” (tipping the scale further). Hence, when the innovation is new to an area and the number of existing “adopters” is low, dis-adoption and subsequent “negative word of mouth” is innately a stronger force in comparison to positive word of mouth. This highlights the importance of extension support to eliminate a proportion of dis-adoption, especially in the early phases.

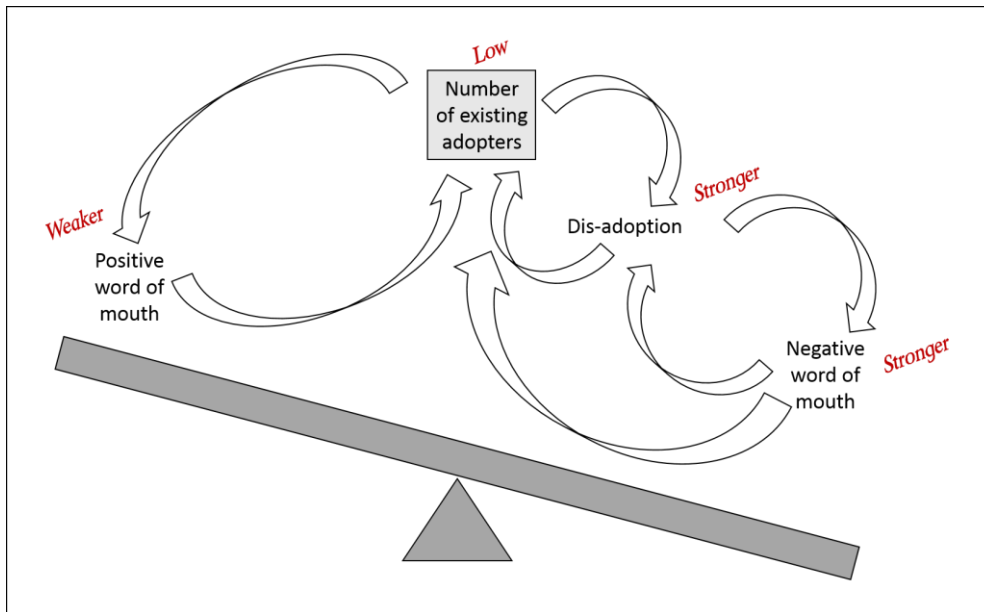


Figure 5.24 Summary of the relative strength of the causal forces when number of existing adopters is low

Finally, the strength of positive word of mouth is weak when the number of adopters is low. This begs the question as to what motivates the initial group of farmers to adopt if it was not positive word of mouth. Understanding this can also, perhaps, reveal a new lever for increasing the number of early adopters who can give birth to positive word of mouth. The reader is reminded that in Chapter 4, the narrative data and evidence from literature also raised ‘learning and gaining personal experience via mechanisms such as small scale on-farm testing’ as an important process for the earlier adopters. This is explored further in the next chapter.

6. RESULTS (PART 3): MODELLING ON-FARM TESTING

The model presented in the previous section was a community scale model. The units of the stocks in the model was number of farmers. In other words, the model viewer was afforded an opportunity to gain insight on the initial distribution of farmers in the stock and flow chain, and the how the causal forces dynamically result in the movement of farmers within a community. This was appropriate to explain the dynamics of word of mouth. In this chapter, an on-farm testing model was conceptualised to explore the mental dynamics of early adopters at an individual scale. What occurs within the mind of any given early adopter when going through the adoption process? When an innovation first arrives in a community, there are no existing adopters and therefore no word of mouth within the community. Hence, early adopters tend to lean towards testing and experiencing for themselves in order to make the adoption decision (evidence from literature presented in Section 4.1.2). Some early adopters may refer to family and friends in other parts of the country to gain initial knowledge. The predominant way of learning, however, is to test the innovation on a small scale on their own farms.

The link between the word of mouth model in the previous chapter and the on-farm testing model, to be presented in this chapter, is conceptually presented in Figure 6.1. The conceptual link was synthesised from the literature and narrative data presented in Chapter 4. If an innovation proves successful in an on-farm testing process, the early adopters will share the idea and their success with other farmers in the community (through word of mouth). Some farmers will take heed of the information but will still not have enough confidence to adopt. These farmers having accumulated some information, via word of mouth, still have the need to test the innovation on their own farms before adopting. The remainder of the population is not so keen to go through the pain of on-farm testing, and prefer to wait and watch how others fare. The majority of farmers will make the adoption decision based on the strength and direction of 'word of mouth' signals from peers in the community. The process is schematically depicted in Figure 6.1.

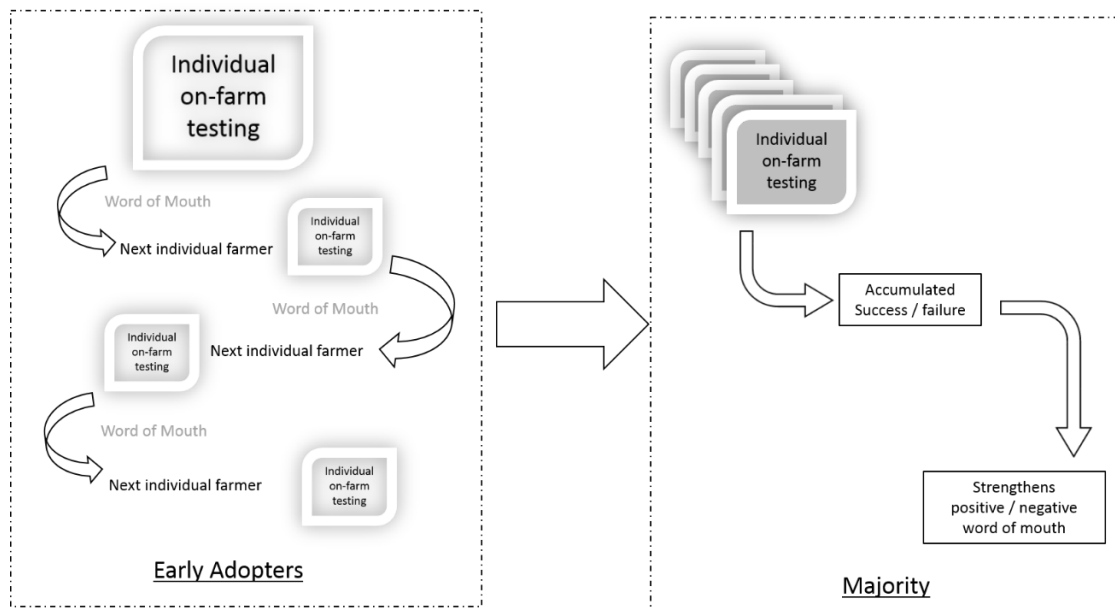


Figure 6.1 Conceptual link between word of mouth and on-farm testing in a farming community

The two system dynamics models aimed to capture and explore independently each of these facets, word of mouth and on-farm testing. The individual system dynamics models are not physically linked, because they operate at different scales. The on-farm testing model operates at the individual level, while the word of mouth model operates at the community level.

Different from the word of mouth model, the on-farm testing model in this chapter is presented in a simplified manner. Many of the variables important for mathematical formulation have been omitted in the Figures. These variables make the model map messy and confusing. Hence the causality is described in a narrative manner, rather than in a clinically mathematical manner. Based on the evidence from literature and the narrative data, presented in Chapter 4, the on-farm testing theme was of specific interest. The model was constructed with the intention of exploring how on-farm testing is stimulated in reality.

Similar to the word of mouth model, the on-farm testing model in this chapter is developed incrementally introducing bite size model elements logically. The model elements include:

- increasing internal motivation to stimulate on-farm testing,
- drainage of internal motivation due to low knowledge levels and
- introducing different types of knowledge which either increase motivation or prevent the drainage of motivation.

Following the logical formulation of the model structure in Section 6.1, the results from simulation experiments is presented in Section 6.2.

6.1 Conceptualisation and Formulation of On-Farm Testing Model

All action is underpinned by a desire, a motivating factor. Even inaction is based on some motivating factor/desire. For example, inaction could be based on the desire to avoid the pain associated with change. The balance of positive and negative motivational forces, therefore, explains the resultant action or in-action. Hence it is intuitive that to induce behaviour change, enough of the right motivation must be stimulated. In the context of exploratory modelling (to better understand the dynamics of irrigation scheduling), a stock titled “motivation to schedule irrigation” was conceptualised. Logic suggests that scheduling of irrigation does not take place when the motivation to do so is low. There is no data or literature to support this statement. This model fragment which includes the “motivation” stock is considered novel and is being proposed as a theoretical framework. Furthermore, we can surmise that “motivation” must be increased to some trigger or tipping point for action to be initiated. In this case the desired action will be on-farm testing of an innovation to schedule irrigation. In the absence of data, the tipping point for the “motivation” stock to trigger on-farm testing was set at 40 %.

Intuitively, knowledge dissemination and extension activities have predominantly focused on stimulating the growth of enough “motivation”. Depicted in Figure 6.2, a traditional approach to increase the motivation was to promote (make visible) the benefits (relative advantage) of the innovation/BMP (Rogers, 2003; Pannell *et al.*, 2006). Pathways for communicating the benefits of the BMP include grower and field days, printed media and farmer study circles. Hence, increasing “learning experiences” increase the “perception of relative advantage” which increases the “number of motivating experiences” and, ultimately, the stock of “motivation to schedule irrigation”. In addition, a farmer can also “realise real benefits” from on-farm testing, which will further contribute to increasing motivation. The effect of realising “real benefits” will be developed later.

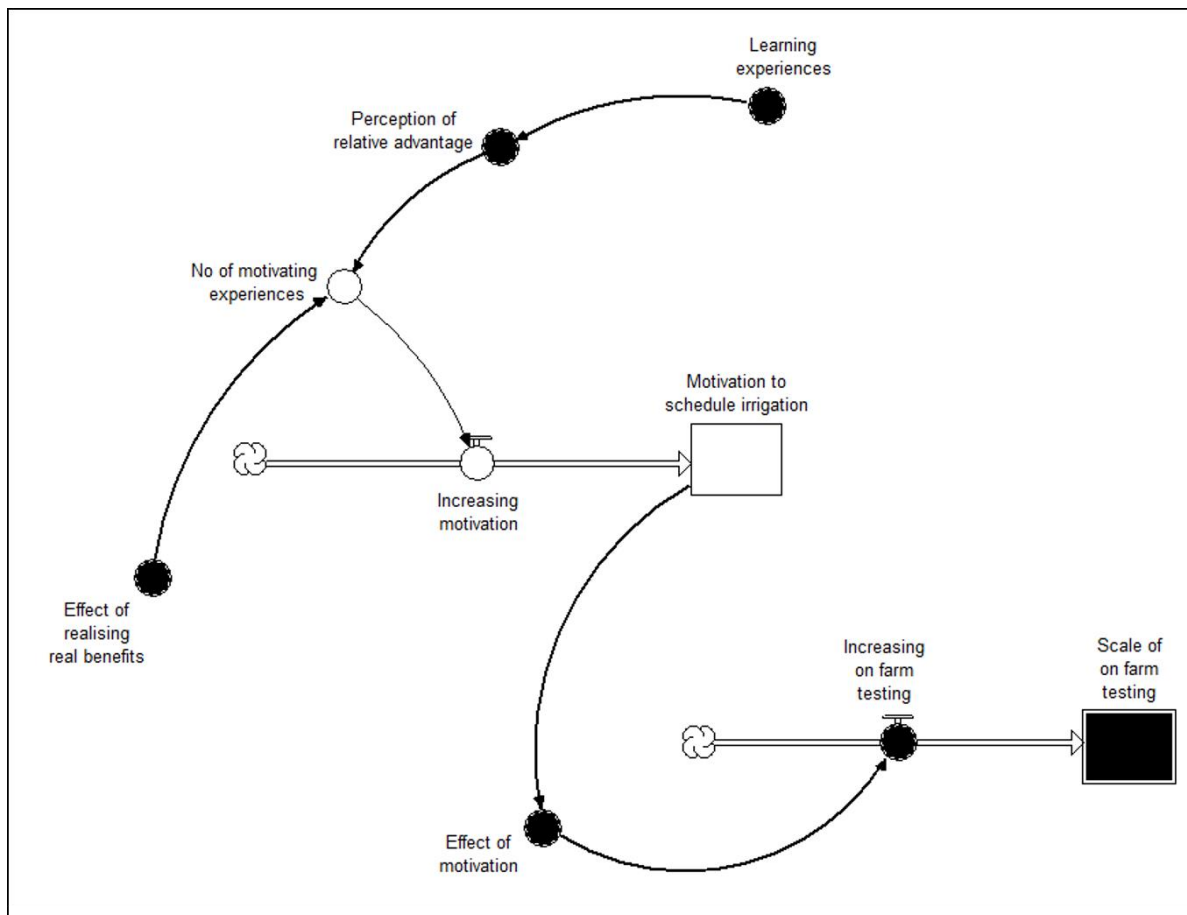


Figure 6.2 Traditional extension approach to increase adoption by promoting the benefits (relative advantage) of a BMP

In an international sugarcane workshop on adoption, participants, which included agricultural engineers, agronomists and extension specialists, were asked to list and rank the most important characteristic traits of an innovation for encouraging adoption. Economics, in the form of a cost-to-benefit ratio or relative advantage was overwhelmingly reported as the most important variable in the group discussions for improving adoption (Jumman *et al.*, 2016). Hence, promoting the benefits of irrigation scheduling in economic terms appears to be a clear and obvious pathway for increasing the “motivation” stock. In the South African sugarcane industry, however, of the 18 irrigation scheduling popular press articles prepared by SASRI specialists since 1992, only 4 makes mention of economics in Rand terms. None of the 4 can qualify as cost-to-benefit assessments for the purposes of promoting the adoption of irrigation scheduling. In some instances, researchers did report on the yield increase and/or water savings realised from irrigation scheduling, but failed to report on the actual costs and the benefits in economic terms. Improving SASRI’s effectiveness in reporting the economic benefits, is one avenue for improving the adoption of irrigation scheduling.

Promoting benefits, however, is only one structural entry point in the system. If the “perception of relative advantage” is the only focus and effort and resources are poured into mastering this aspect, other forces in the system may get neglected. These other forces can easily override the effect of better promoting the benefit for irrigation scheduling. It is important to consider the other entry points/forces in the system.

Hence, in Figure 6.3, an outflow which operationally drains the motivation stock was introduced. The outflow was called “losing motivation”. Reflecting on literature in Section 4.1.2 and the narrative data collected from extension specialists in Section 4.2.2, it was credible that a farmer loses motivation when he was unsure. When the risk was perceived to be too high. The desire to act can easily be weakened when there is doubt and uncertainty. Hence, losing motivation is associated with the farmers’ “perception of risk and uncertainty” associated with the innovation (Pannell, 1999; Marra *et al.*, 2003; Pannell *et al.*, 2006). Furthermore, when the “learning experiences” are low (i.e. poor knowledge level about the innovation), the “perception of risk and uncertainty” is expected to be high, subsequently resulting in a higher tendency for motivation to drain out via the “losing motivation” flow.

The model structure allows for the following credible scenario to play out. A farmer can initially become excited when he learns of the benefits of a new irrigation scheduling tool. However, if the farmer is not able to ascertain any further information such as:

- Where can the product be purchased from?
- How easy is it to install and operate?
- Is training required?
- Is it easy to use?
- Where is it already being used successfully?
- If there is a problem, who will be available to help?

If the answers to these questions, for example, are not available, the low knowledge levels will allow for doubt and uncertainty to arise, causing the initial excitement to drain out and prevent the farmer from finding out more or purchasing the so-called exciting new product.

In addition, shown in Figure 6.3 is the variable “real risk and uncertainty”. This element is to formally acknowledge that any innovation with a real flaw will be a non starter. The “real risk

and uncertainty” variable is programmed as an on and off switch. When the switch is turned on, the innovation is flawed, and the model will set the “losing motivation” outflow to a very high value such that the “motivation” stock will never accumulate enough to trigger “on-farm testing”. When the switch is turned off, the variable is disabled and not influential in the model. The model is normally operated with the switch turned off, assuming that existing irrigation scheduling tools are technically sound and appropriate for use by farmers.

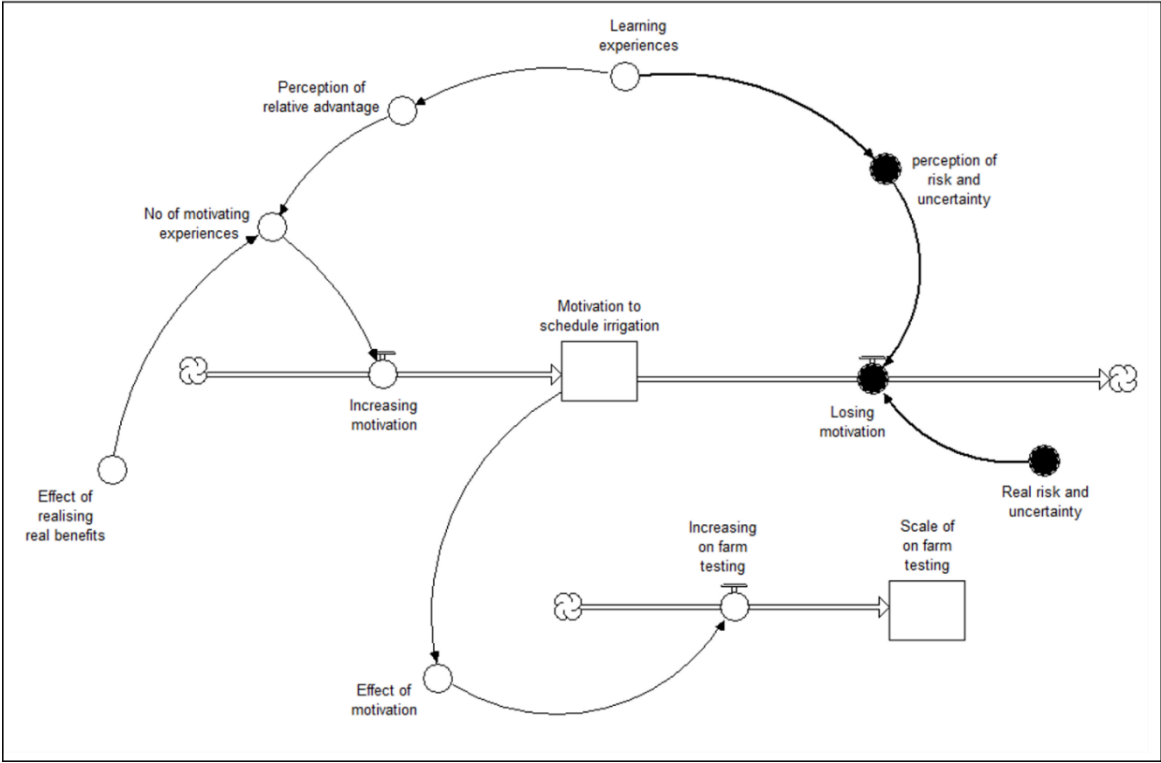


Figure 6.3 The drainage flow “losing motivation” which arises from “perception of risk and uncertainty”

The model structure reveals that it is necessary to increase “motivation”, while simultaneously limiting the outflow of motivation. The failure to do so in the real world is captured in literature. Vanclay (2004), for example, suggested that scientists often work in isolation and fail to understand the world view and complex reality under which farmers operate, resulting in incompatible tools and misaligned recommendations. Stirzaker (2010) also noted that the goals of scientists are often different from farmers. In the context of the above discussion, the goal of the scientist to make visible the economic benefit of a BMP is different from the farmer, who in addition to understanding the benefits also requires information that will help to ease any uncertainty and doubt.

Extension specialists have suggested that the best way to provide relief from the “perception of risk and uncertainty” is for scientists to spend more time with farmers. In this way, scientists get the opportunity to better understand the farmers’ needs and concerns, and to develop a relationship and gain trust from the farmer. Scientists can then assist extension to provide farmers with the necessary knowledge to release a portion of the unnecessary/excessive “perceptions of risk and uncertainty” so that a farmer can accumulate enough “motivation” to initiate “on-farm testing”.

Only first-hand experience, via “on-farm testing”, can completely eradicate “perceptions of risk and uncertainty”. The above discussion, however, suggests that an initial effort is required, in the form of both increasing “motivation” and limiting loss of “motivation”, to help a farmer get to the stage where “on-farm testing” is a comfortable and attractive proposition.

Care must be taken not to misinterpret the model structure. It may be tempting for one to view the model structure in Figure 6.3 and conclude that SASRI, for example, merely need to increase the number of “learning experiences” in order to improve adoption. More grower days and/or written media, for example, could easily become the call of the day. It has already been reported that creating awareness is not enough. Positive interventions in the persuasion stage when growers are formulating opinions about the innovation are also necessary (Rogers, 2003). To avoid this misinterpretation of the model structure, the concept of “learning experiences” was further refined.

In Figure 6.4, “learning experiences” facilitate a process called “information acquisition” resulting in the accumulation of knowledge. Initially, knowledge, in this model, is expressed as two different stocks. The first stock represents the knowledge a farmer may have on the relative advantage of the BMP. The knowledge stock is not attributed with any units of measurement, but can be scaled with values between 0 and 100. The knowledge stock value was assumed to be zero initially. “Knowledge of relative advantage” increases as information is acquired via “learning experiences”.

Purposefully, a second knowledge stock was introduced. This is the stock of knowledge a farmer may have of the innovation and its attributes. It represents the farmer’s knowledge on the characteristic traits of the innovation. Guided by the literature, this knowledge encompasses aspects of the innovation which relate to ease of use, technical soundness, practicality and

ability to test and trial on a small scale, for example (Rogers, 2003 and Pannell *et al.*, 2006). In an Australian initiative, a computer model, named ADOPT, was developed to predict the level and speed of adoption based on the inherent characteristic traits of the innovation (Kuehne *et al.*, 2012). The ADOPT tool was used at the project proposal and application for funding stage, to decide upon the allocation of funds. This emphasized the importance for scientists to take cognisance of the important characteristic traits of an innovation and its subsequent role in influencing adoption. In this thesis, the idea is expanded upon, by proposing that it is equally important for the knowledge of these specific innovation characteristics to be communicated and/or demonstrated for farmers. The essence of this knowledge is different from that of relative advantage. For this reason, the two separate knowledge stocks are made explicit (Figure 6.4).

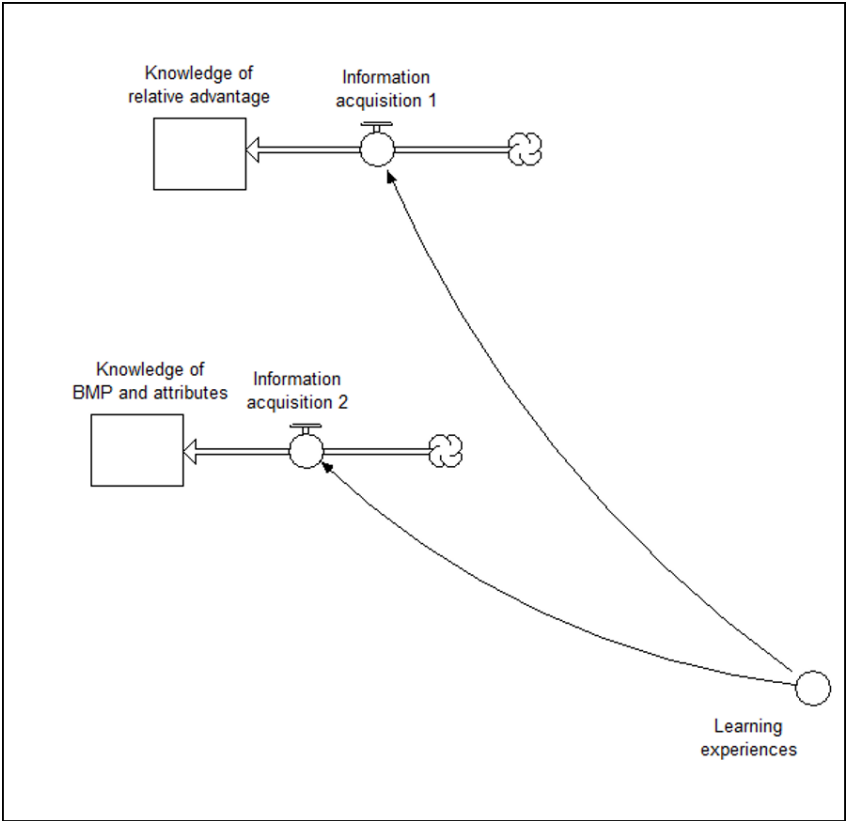


Figure 6.4 Explicit representation of different knowledge stocks

The intention was to transparently map the causal pathways of the two different types of knowledge. Also, it was necessary to highlight that the content of a learning experience will dictate to which knowledge stock the acquired information will contribute. Consider that at a grower’s day event, a presentation on the performance of the innovation will help to increase the “relative advantage knowledge” stock. Alternatively, a field day, where a peer demonstrates

the innovation and shares his experiences, may serve to increase the “knowledge of BMP and attributes” stock. A purposeful and focused effort is required to fill up the explicitly different knowledge stocks. Mapping the structure of the system on a system dynamics platform in this way, allows for knowledge management units and extension specialists to reflect on past knowledge exchange practices, and to ask key questions such as: Which stock has received adequate attention and which one has been neglected? What proportion of time and effort has been spent on each stock? This functionality is built into the model by introducing the variables “proportion to relative advantage” and “proportion to attributes”, illustrated in Figure 6.5. Both variables are dials which can be set at a value between 0 and 1, apportioning the fraction of “learning experiences” between the two knowledge stocks accordingly. Hence the model can adequately represent and simulate a bias, equal efforts or some proportionate splitting of the “learning experiences” towards the different knowledge stocks.

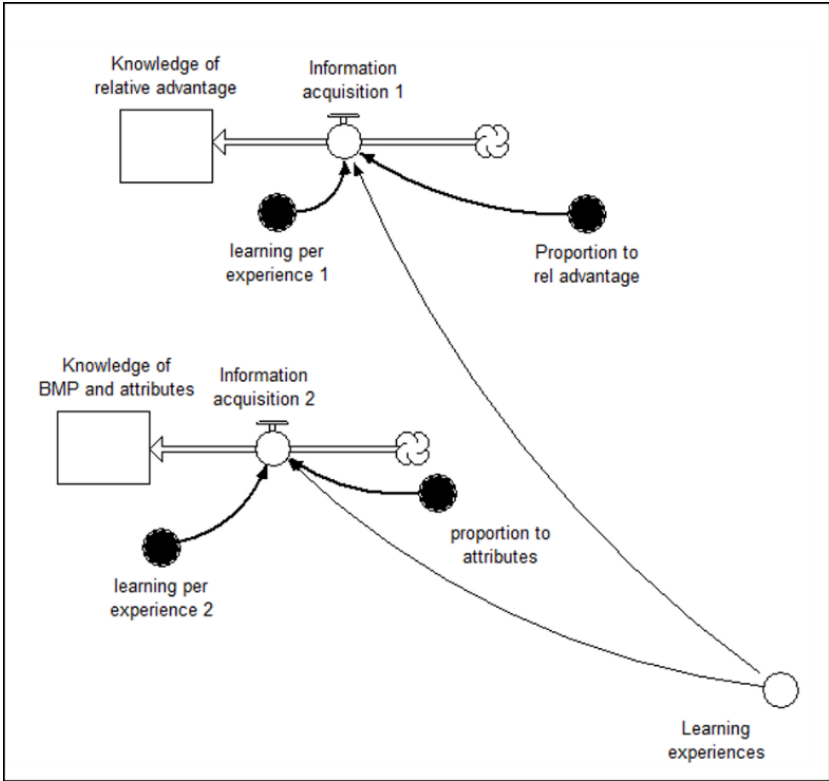


Figure 6.5 Modelling the ability to apportion the effort required to grow the respective knowledge stocks

As mentioned earlier, there is a danger of misinterpreting the model and wrongly concluding that increasing the number of “learning experiences” will solve the problem. Apart from proportioning the appropriate effort to the different knowledge stocks, one can also effect

change by altering the quality (depth) of the learning experience. This is captured in the model by a variable titled “learning per experience” (1 & 2). The “information acquisition” flow is equal to the number of “learning experiences” (per unit time), multiplied by the proportion variable, and multiplied by the “learning per experience” variable. The “learning per experience” variable makes explicit that the learning experience can differ in quality. Knowledge exchange agents are provided with the opportunity to reflect on the quality and depth of learning from different activities. The typical knowledge exchange and extension activities are shown in Figure 6.6. The array of activities which stimulate “learning experiences” include “one on one extension”, “peer interaction” (word of mouth), “printed media”, “grower days”, “study circles” and “field days”.

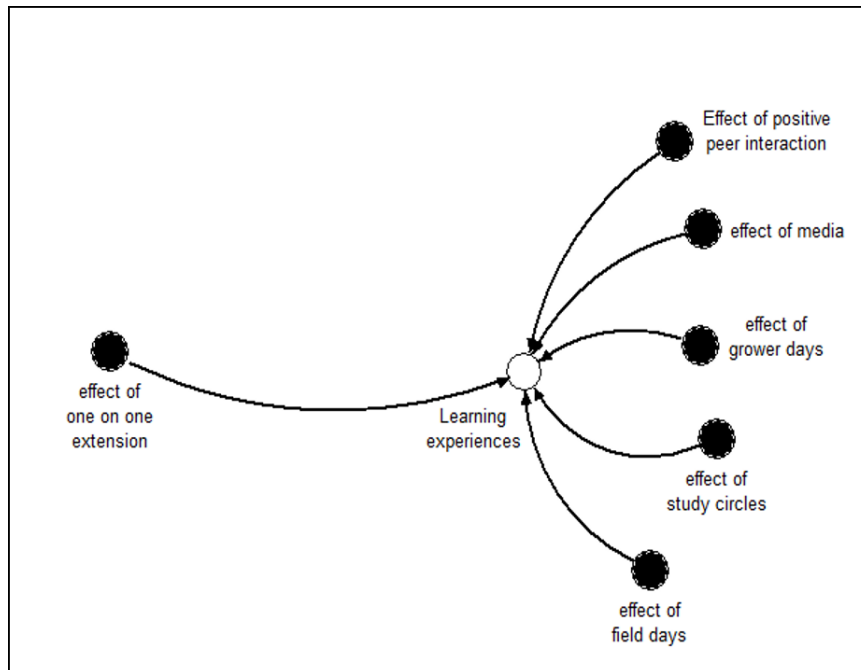


Figure 6.6 Illustrating the multiple pathways available to stimulate “learning experiences”

Positing the theoretical framework into the model structure in this way, allows for the formulation and communication of various hypotheses for improving the uptake and adoption of innovations such as irrigation scheduling. In this case, the explicit hypothesis is that the quality, directional proportion and number of learning experiences can be used to fill up low knowledge stocks in the minds of early adopter farmers, in order to simultaneously stimulate the accumulation of “motivation” to implement the innovation, and to limit the drainage of such motivation, until enough “motivation” is acquired to spur on an individual to test the innovation on their own farms. No single intervention is likely to achieve the goal on its own. Instead the

combination of variables must be tuned, in correct proportions, to work together in the causal system. To truly understand the system dynamics, the causal model will now be presented holistically.

If the “perception of risk and uncertainty” is high in the real world, a farmer usually looks to the extension specialists for guidance. It was clear from the narrative data in Chapter 4 that farmers use extension specialists as sounding boards. The signal from farmers about their “perception of risk and uncertainty” usually triggers an extension interaction with the farmer. For example, the extension specialist, via a personal visit to the farm, a phone call or an email with published information, may try to reduce the farmer’s doubt. A “learning experience” may be initiated to remind the farmer of the relative advantage of the innovation. In Figure 6.7, the “knowledge of relative advantage” stock is linked to the “perception of relative advantage”, i.e. as the knowledge levels increase, the “perception of relative advantage” increases making the innovation more attractive and increasing the stock of “motivation to schedule irrigation”. Increasing the “knowledge of relative advantage”, however, only serves to increase the inflow of “motivation to schedule irrigation”. It does not address the drainage flow due the high “perception of risk and uncertainty”. Hence, increasing the 1st knowledge stock is less effective in this instance.

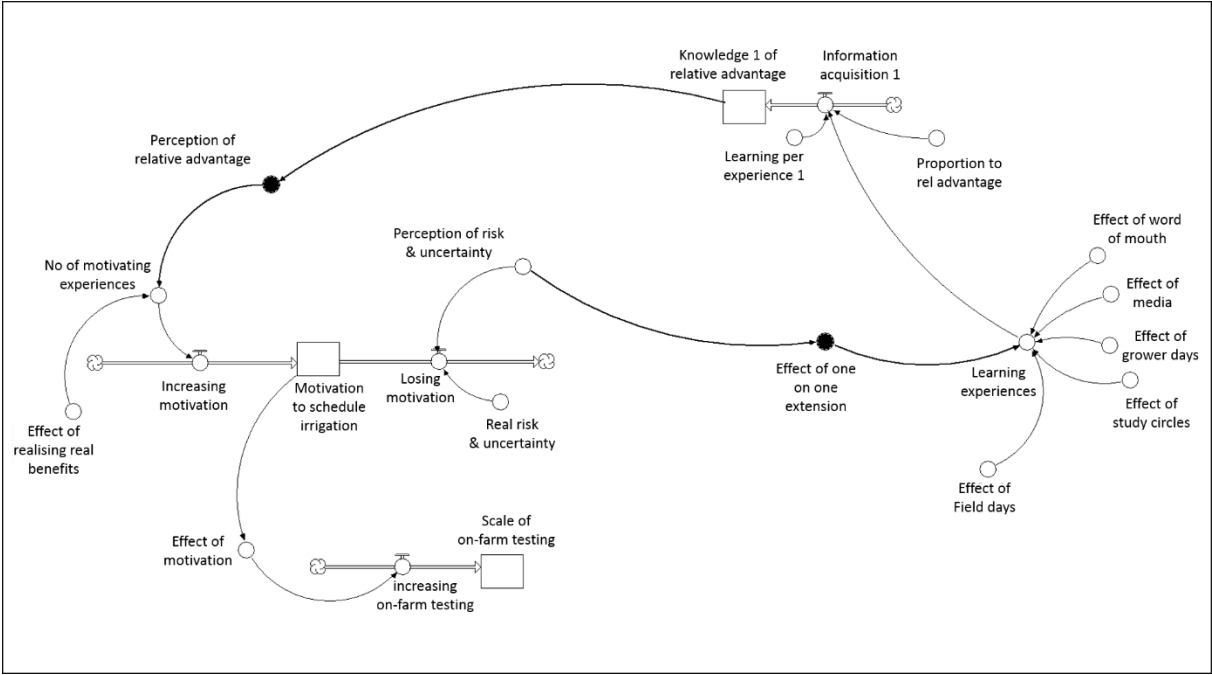


Figure 6.7 A causal link between the “perception of risk and uncertainty” and “one on one extension” activity

A more effective entry point in the system is revealed in Figure 6.8. The second knowledge stock, “knowledge of the BMP attributes” is linked to the “perception of risk and uncertainty”. Take note, the relationship here is an inverse relationship. When the knowledge levels are low, “perceptions of risk and uncertainty” are high. Conversely, increasing the “knowledge of the BMP attributes”, gradually decreases the “perception of risk and uncertainty”. The theory being proposed, and embedded in the model structure, suggest that the more the farmer learns, the more comfortable he becomes with the innovation, which in turn weakens the drainage flow “losing motivation”. Hence the extension specialist should try to apportion some learning experiences towards the growth of the second knowledge stock.

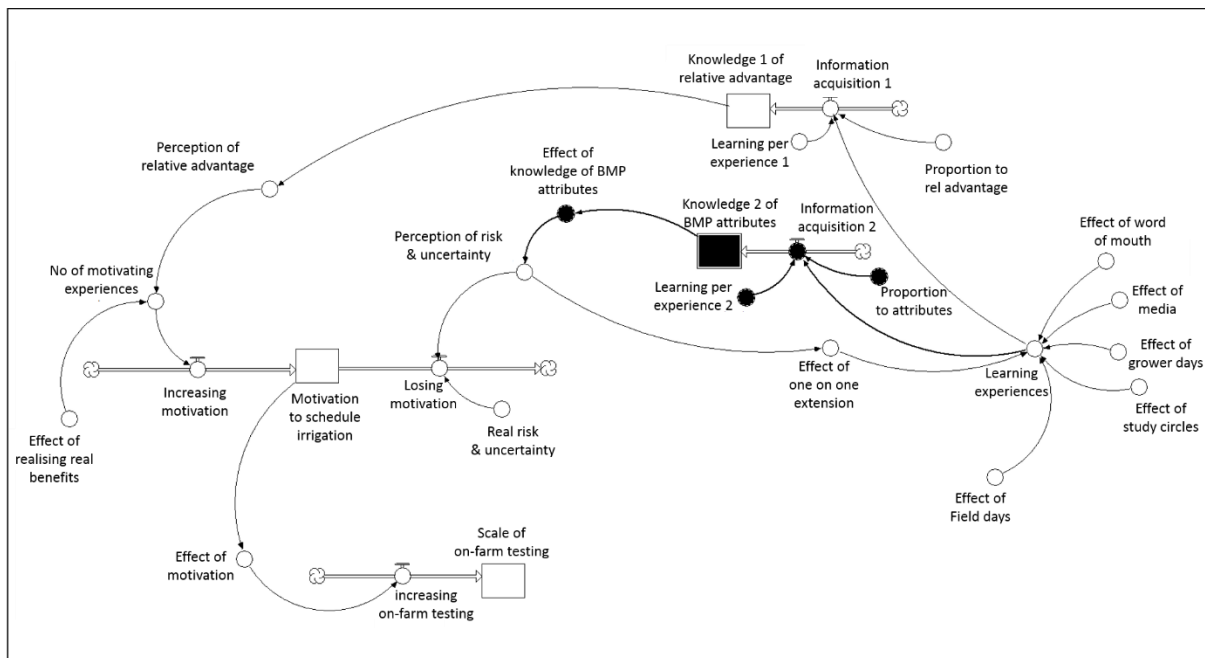


Figure 6.8 A causal pathway for reducing the “perception of risk and uncertainty”

Attaining maximum “knowledge of the BMP attributes” (represented by a full knowledge stock 2 in the model), however, does not eliminate all the “perception of risk and uncertainty”. The model was configured such that learning all that one can about a certain innovation will only help to eliminate 50 % of the “perception of risk and uncertainty”. The explicit assumption (proposed theory) is that gaining knowledge from others, via “information acquisition 2” is inadequate on its own. A farmer must also experience the innovation for himself. Hence, the model was further developed such that the remaining 50 % of “perceived risk and uncertainty” can only be eliminated by a farmer’s personal experience with the innovation, i.e. “learning by

doing”. Amir *et al.* (1999) and Pannell *et al.* (2006) clearly establish the difference in “information acquisition” and “learning by doing”, to reduce uncertainty in farmers’ minds. This past literature, however, did not specify numerically, the extent or limitation to which each pathway could reduce uncertainty. In this system dynamics model, assigning a reduction of the “perception of risk and uncertainty” by 50 % for each knowledge stock was an explicit assumption in order to make the model operational. There is no data or easy way to test in the real world if perceptions are reduced to these exact numbers. Similar to the word of mouth model, the intention was not to formulate a predictive model. For this reason, the absolute values were considered to be relatively less important in comparison to the underlying causal structure, which exposes the different entry points into the system.

In Figure 6.9, a third knowledge stock, titled “implementation knowledge”, was introduced into the model. Figure 6.9 illustrates the complete model map and a larger printer friendly version is available in the Appendix (Figure 9.2). Significantly, the inflow which is used to grow the “implementation knowledge” stock was titled “learning by doing”. It stands to reason that one can know all about an innovation, in terms of both the relative advantage and the innovation’s attributes, but may know nothing about implementing and successfully using the innovation. Hence, the 3rd knowledge stock is distinctly different from the other two.

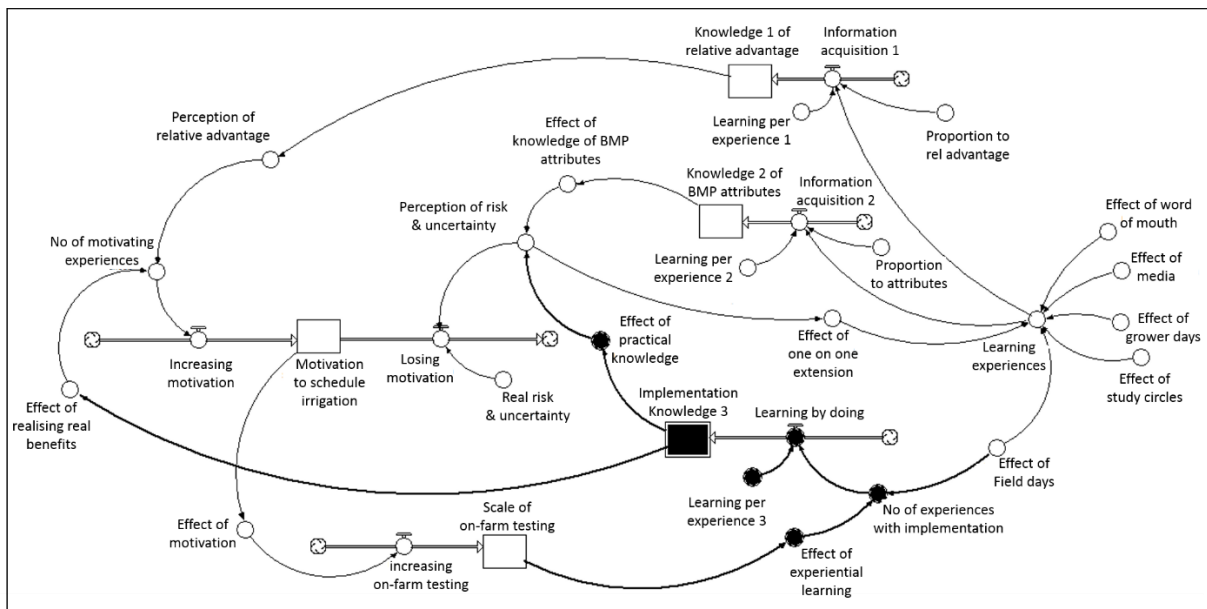


Figure 6.9 The structural layout of the on-farm testing model

While distinctly different, knowledge stocks 2 and 3 primarily operate in the same causal direction, i.e. when knowledge levels are low, “perception of risk and uncertainty” are high and, an increase in either of the knowledge levels can reduce the “perception of risk and uncertainty”. The “perception of risk and uncertainty” is only eliminated when both the knowledge stocks achieve the maximum level. An unlikely event!

Furthermore, the driver to increase the “implementation knowledge” stock level is different from the other knowledge stocks. Here, “information acquisition” from others via exposure to “learning experiences” is irrelevant. It is necessary for the farmer to gain direct personal experiences with implementing the innovation. Hence, the “effect of experiential learning” (learning from experience) from “on-farm testing” is the main avenue for creating the opportunity to “learn by doing”. To a lesser degree, “field days” where other farmers demonstrate the innovation and share their experiences can also contribute to the growth of the “implementation knowledge” stock.

Finally, in Figure 6.9, the “implementation knowledge” stock is also linked to the “realizing real benefits” variable. The explicit assumption was that if the innovation was not flawed, and the on-farm testing of the innovation was conducted correctly, the growth in the “implementation knowledge” further stimulates the “number of motivating experiences”, via the “effect of realising real benefits” from on-farm testing.

This concludes the conceptualisation and formulation of the ‘on-farm testing’ model. The reader is reminded that the “scale of on-farm testing” is being used as a proxy for adoption by a single farmer. Adoption is a process, where learning and experience were considered important precursors, especially for the earlier adopters in a community before word of mouth becomes active. If the individual initiates on-farm testing and experiences a degree of success, the scale of testing can be incrementally increased, until a stage is eventually reached when testing is converted to incremental implementation across the entire farm area, i.e. full scale adoption.

It is also important to note that the stock “motivation to schedule irrigation” is novel. Farmers’ “knowledge” and “perceptions about the risk, uncertainty” and “relative advantage” of an innovation is apparent and visible in the literature (Section 4.1.2). Concepts such as “information acquisition” and “learning by doing” via on-farm testing are also well documented

in the literature (Section 4.1.2). Referring to the iceberg analogy (Figure 3.4), the three knowledge stocks and the “perceptions of relative advantage” and “risk and uncertainty” are much like the visible components of the iceberg. In the context of this chapter, the “motivation to schedule irrigation” (stock) was a less visible element, resonating with the portion of the iceberg which lies below the water surface, but dictates behaviour. Due to the nature of motivation, especially amongst scientists, “motivation” is a less visible and difficult to quantify variable. It has been introduced in this model as a central model fragment. The “motivation” stock is a piece of the model puzzle, which, when placed structurally as it has been, helps to explain or even define the causal direction and influence of the other model fragments in the context of behaviour by an individual farmer. In this way, the model (and the embedded theoretical framework) contributes to advancing the science by extending beyond the past practice of listing key variables as important. In the on-farm testing model, the central “motivation” stock pulls the other model fragments together to demonstrate how the variables work together as one system. For this reason the “motivation” stock is considered to be similar to the influential, but less visible structure below the water surface in the iceberg analogy. Making the model structure explicitly visible in this way allows for meaningful engagement with the complex web of cause and effect relationships. In the next section, simulation experiments help to deepen the engagement and understanding of the dynamic complex system.

6.2 On-farm Testing Simulation Experiments

Similar to the word of mouth model, it was necessary to configure the on-farm testing model with plausible initial condition and default values (see Table 6.1). Initially, all stocks are assumed to have a value of zero, corresponding to a case where irrigation scheduling is not present in the mind of the individual farmer. The “on-farm testing” stock (units: ha) was set with a range from 0 – 50 ha. In other words, 50 ha was assumed to be the maximum area that a farmer will use for testing an irrigation scheduling innovation. Expansion beyond 50 ha, will typically translate to adoption and whole farm implementation. The default values in Table 6.1 are the same as the values used for scenario 1 in Table 6.2 and will be discussed later.

In the system dynamics model, the strength of the pathways for creating “learning experiences”, or lack thereof, was modulated by two input parameters, “magnitude” and “frequency”. To keep the image from becoming too messy, these variables were not made transparent in the stock

flow diagram. Instead they are shown in Table 6.1. “Magnitude” is an indicator of the effectiveness of the effort, either via “written media”, “grower days” or “study circles”. “Frequency” details the regularity of effort, so as to ensure that farmers have every opportunity to appreciate the “importance of the BMP or innovation being promoted. Furthermore, the variable “initial” also allows the end user to stipulate the occurrence of the first event. For example, if the “effect of grower day” variable is set with a magnitude of 3, frequency of 6 and the initial value of, say 8. The model will simulate a “learning experience” equivalent to the value of 3 (magnitude) in the 8th month (initial) from the start of the simulation period and repeat the “learning experience” every 6 months (frequency) after the initial event. In the model default setting, 80 % and 20 % of the “magnitude” value 3 will be directed towards “information acquisition 1 and 2”, respectively, in the same time unit as the “learning experience” was simulated.

Modelling experiments are used to discover what is causing the current undesired behaviour, and to also consider what variables are available for adjusting the behaviour towards a desired state. In this case, the undesired behaviour is no or low “motivation” to test or adopt irrigation scheduling tools. Table 6.1 should provide the reader with a view of what variables are available, both in the real world and in the model, to adjust stock behaviour.

Table 6.1 Initial condition, default values and the variable range for on-farm testing model

No	Variable (stocks)	Initial Condition	Range
1	Scale of on-farm testing (ha)	0	0 – 50
2	Motivation to schedule irrigation	0	0 – 100
3	Knowledge 1 of relative advantage	0	0 – 100
4	Knowledge 2 of BMP attributes	0	0 – 100
5	Implementation Knowledge 3	0	0 – 100
No	Variable (Parameters)	Default Value	Range
1	Proportion to relative advantage	0.8	0 – 1
2	Proportion to attributes	0.2	0 – 1

Table 6.1 Continued...

No	Variable (Levers)	Default Value	Range	
1	Effect of media	Magnitude	1	0 – 5
		Frequency	1 in 12 months	0 – 12
		Initial	3 rd month	0 – 12
2	Effect of grower days	Magnitude	3	0 – 5
		Frequency	1 in 12 months	0 – 12
		Initial	8 th month	0 – 12
3	Effect of study circles	Magnitude	0	0 – 5
		Frequency	0	0 – 12
		Initial	0	0 – 12
4	Effect of field days	Magnitude	0	0 – 5
		Frequency	0	0 – 12
		Initial	0	0 – 12
5	Magnitude of one-one extension	0	0 – 5	
6	Magnitude of positive word of mouth	0	0 – 5	

In an exploratory manner, scenarios 1, 2 and 3, in Table 6.2, have been formulated to conduct modelling experiments, in order to illustrate, test and learn more about the on-farm testing paradigm and its potential for improving the adoption of irrigation scheduling in the case study area.

Table 6.2 Summary of inputs used for simulation experiments

No	Variable	Scenario 1	Scenario 2	Scenario 3	
1	Proportion to relative advantage	0.8	0.8	0.5	
2	Proportion to attributes	0.2	0.2	0.5	
3	Effect of media	Magnitude	1	2	2
		Frequency	1 in 12 months	1 in 6 months	1 in 6 months
		Initial	3 rd month	3 rd month	3 rd month
4	Effect of grower days	Magnitude	3	4	4
		Frequency	1 in 12 months	1 in 8 months	1 in 8 months
		Initial	8 th month	8 th month	8 th month

Table 6.2 Continued...

No	Variable	Scenario 1	Scenario 2	Scenario 3	
5	Effect of study circles	Magnitude	0	5	5
		Frequency	0	1 in 3 months	1 in 3 months
		Initial	0	1st month	1 st month
6	Effect of field days	Magnitude	0	3	3
		Frequency	0	1 in 8 months	1 in 8 months
		Initial	0	8th month	8 th month
7	Magnitude of one-one extension	0	4	4	
8	Magnitude of positive word of mouth	0	5	5	

Scenario 1 represents a baseline scenario, indicative of the traditional mode of operation. Adendorff *et al.* (2016) details the customised extension approach used in the case study area for the period 2009 - 2015. With no extension services in prior years, the new extension specialist in the case study area identified and focused on pest and diseases, clean seedcane and varieties, and chemical ripening to increase sucrose content as the main extension focal areas. As a result, scenario 1 represents an idling mode where no or minimum effort is put into promoting a specific BMP, in this case irrigation scheduling.

This was plausible, since farming entails many aspects and disciplines and the extension specialists, was justifiably focusing on other areas resulting in no or minimal effort towards the promotion of irrigation scheduling. In scenario 1, “learning experiences” are proportioned to the “knowledge stock 1 and 2” as per the default. The default represents status quo, i.e. it was assumed that 80% of the effort to promote a BMP or innovation is directed towards increasing the “knowledge of the relative advantage”. Only 20 % of the effort is assumed to focus on increasing the “knowledge of the attributes” of the innovation for the purposes of reducing doubt. This was also plausible based on observed signals from the real world (Adendorff *et al.*, 2016 and Jumman *et al.*, 2016).

Hence, in scenario 1, minimal effort was represented by only 1 written “media” article and 1 “grower day” every 12 months, with a “magnitude” of 1 and 3, respectively. In the real world, this was representative. In the exploratory interviews, signals had come through from growers

indicating unhappiness that the media was not being published in Afrikaans, the grower's preferred language (data not shown). Hence, a low media "magnitude" of 1 was allocated. In addition, scanning the SASRI publication records revealed that, historically, on average growers were exposed to 1 article on irrigation per year (Olivier and Jumman, 2010; Jumman and van der Laan, 2011; Singels, 2012; Jumman, 2015).

The "effect of grower days" was assigned a "magnitude" of 3. This was based on the effort and success in irrigated regions to encourage the uptake of chemical ripening (van Heerden, 2014 and Adendorff *et al.*, 2016). The extension specialist revealed that irrigation scheduling was always mentioned at grower days focused on chemical ripening (Adendorff, 2014). In the context of chemical ripening, sucrose accumulation is maximised when irrigation scheduling helps to minimise crop stress and ensure vigorous stalk growth during the periods of active chemical action (van Heerden, 2010). Adendorff (2015), indicated that the idea was to use chemical ripening grower days to register and hold irrigation scheduling as important in the minds of farmers, until he was ready to focus on irrigation scheduling as his next key extension theme. Since irrigation scheduling was not a key focus area at that point in time, however, the "effect of farmer study circles", "field days", "one on one extension" and "peer word of mouth" was all assumed to be zero in scenario 1.

Scenario 2 and 3 represent a more aggressive, but realistic, knowledge exchange and extension scenario. All parameters are the same in scenario 2 and 3, except for the proportion of learning experiences allocated to relative advantage and attributes of the innovation. In scenario 2, the default values of 0.8 and 0.2 are assumed for "proportion to relative advantage" and "proportion to attributes", respectively. In scenario 3, the learning experiences are equally proportioned (variables set to 0.5). The increase in magnitude and frequency, and the use of all the learning pathways is indicative of a dedicated and focused effort towards the adoption of irrigation scheduling innovations. Scenario 2 and 3, represent proposed ways of modifying the SASRI or extension effort in future to correct the problem of poor adoption. Tuning the proportion for effort equally towards relative advantage and that of growing "knowledge on the attributes" of the innovations, for example, will have to be learned, designed, practised and/or purposefully implemented by participating SASRI agents in any of the pathways for creating "learning experiences".

The simulation results for scenario 1 are shown in Figure 6.10 below. The reader, is again, encouraged to have the stock and flow diagram available on a separate leaflet, to draw deeper understanding and appreciation of the simulation results. A printer friendly format of the on-farm testing model map is included in Appendix 1. One of the main reasons for developing this system dynamics model was to explore what happens in the mind of an individual leader farmer who is more likely to test an innovation for himself before adopting. The behaviour over time graphs were simulated over a period of 240 months (20 years), as depicted by the x axis. The 1st graph in Figure 6.10 illustrates the results for the 3 different knowledge stocks. Since 80 % of the “learning experiences” was “proportioned towards the relative advantage”, the first stock of “knowledge on relative advantage” grew faster than the second stock of “knowledge on attributes of the innovation”. Interestingly, no feedback loops are active in this scenario, hence the growth in the knowledge stocks are linear. The slope of the knowledge stock curves are also gentle, indicating slow growth, well aligned to scenario 1 which represented small or minimal effort towards promoting the adoption of irrigation scheduling.

The second graph in Figure 6.10 depicts the results for the variables “number of motivating experiences” and “perceived risk and uncertainty”. The third graph illustrates the results for the stocks “motivation to schedule” and “scale of on-farm testing”. Corresponding to the growth in the “knowledge of relative advantage”, the “no. of motivating experiences” gradually increased, further stimulating a subsequent increase in the “motivation stock”. The “knowledge on BMP attributes”, however, did not grow enough to stimulate a reduction in the “perception of risk and uncertainty”. The stock of “motivation”, therefore, never increases enough to reach the tipping point of 40 % in order to stimulate “on-farm testing”. Since “on-farm testing” was never initiated, and no “field days” were allowed as an input into the model, the third knowledge stock, “implementation knowledge”, never rises above the zero level.

Scenario 1 results depict the reference mode of the real world’s undesired behaviour, namely non adoption. Despite some activity or effort in the form of written “media” and “growers days”, and a perhaps a noticeable increase in farmers “knowledge levels about the relative advantage” of irrigation scheduling, farmers were still not testing, and therefore not adopting. This outcome resonated with the current status in the case study area. Growers knew about irrigation scheduling and the importance thereof. Narrative data from the exploratory interviews with farmers confirmed this. One farmer halved his sprinkler stand time from 12 hours to 6 hours to prevent the shallow soils from becoming saturated. In two years, the average yield

increased by 5 tons/ha. This indicated “knowledge of the relative advantage” of good irrigation management. This farmer knew that his rainfall delay rules of thumb for scheduling irrigation were less accurate and had planned to start making use of soil water sensors. The farmer even went to the extent of obtaining quotes for the equipment (a year before the interview with the researcher), but never followed through to adopt, suggesting he got busy on other interventions, such as fertilisers, to increase yield. In the interview he declared that he still planned to use the soil water sensors. Another farmer revealed that he knew about neighbours and friends using tensiometers. He knew how it worked. He wanted to use it. But he just never got around to it. Another farmer even shared how he purchased a tensiometer, but never installed it. It was kept in his office. This farmer shared a story about a friend’s experiences where the tensiometer reading suggested that the soil was wet, but the crop leaves were brown suggesting water stress. This farmer provided signals of some initial excitement, which caused him to purchase the tool, but a prevailing high perception of doubt and uncertainty which prevented him from installing the tool and deriving any benefit.

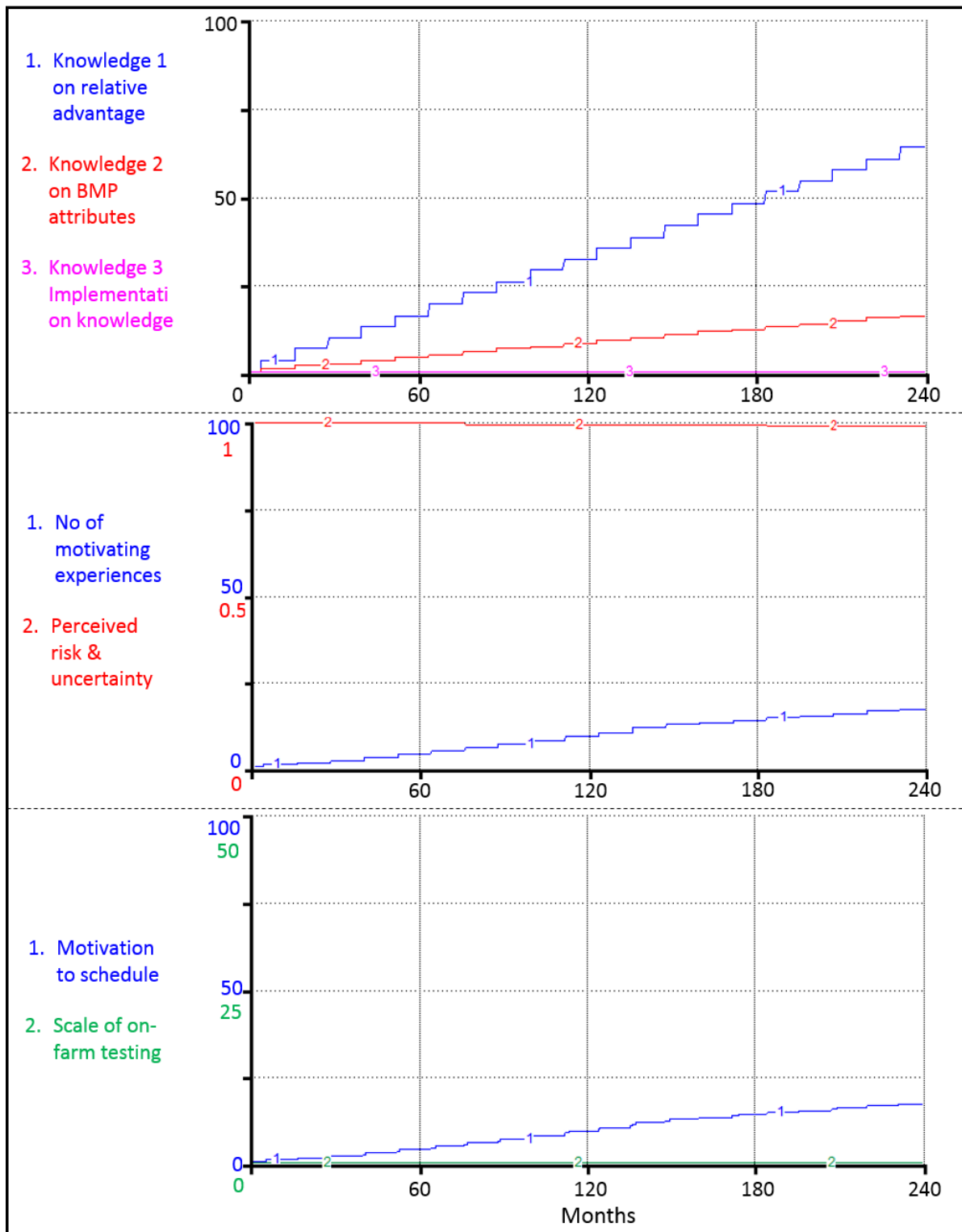


Figure 6.10 Simulation results for scenario 1 (Reference mode: non-adoption)

The results for scenario 2, a more aggressive extension and knowledge exchange strategy, is depicted in Figure 6.11. Like before, the 3 graphs present the 3 knowledge stocks, the “no of

motivating experiences” and “perception of risk and uncertainty”, and the stock of “motivation to schedule irrigation” and “scale of on-farm testing”.

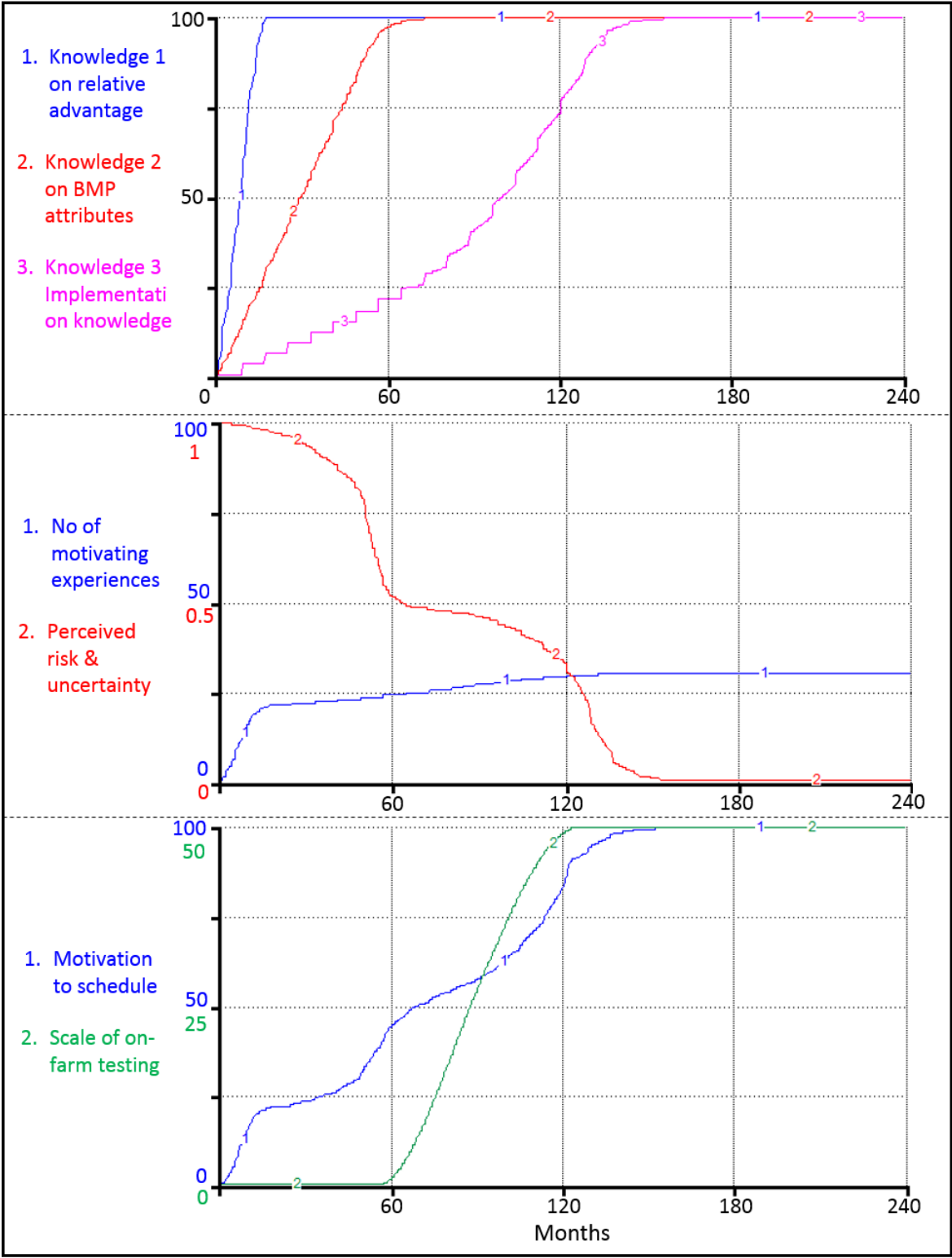


Figure 6.11 Simulation results for scenario 2 (A more aggressive extension strategy)

In scenario 2, the more aggressive extension strategy essentially creates the opportunity for more “learning experiences”. The larger number of “learning experiences” helps an individual to accumulate knowledge on the relative advantage and the “innovation attributes” quickly. Since 80% of the learning experiences were still being proportioned towards relative advantage, the “knowledge on relative advantage” grew more quickly than the “knowledge on attributes”. The knock on effect of the rapid growth of knowledge stock 1 and 2 is an increase in the number of “motivating experiences” and a decrease in the “perception of risk and uncertainty”. The result of which is both an increase in the inflow and a simultaneous decrease in the outflow of the motivation stock. The net effect is a relatively higher and more rapid accumulation of “motivation to schedule”.

Studying the changes in the slope of the “motivation” stock curve, helps the reader to appreciate the systemic relations of the model. The first steep increase in “motivation”, between months 0 and 12, was attributed to the rapidly increasing “knowledge on relative advantage” and subsequent increase in “number of motivating experiences”. After month 12, however, “knowledge on relative advantage” reached a maximum. Hence, the increasing “perception of relative advantage” and the derived experience of “motivating events” also reached a climax. No more motivation could be squeezed out of the “knowledge of relative advantage” causal link. The growth in “motivation” stock slowed down between months 12 and 29. In month 29, the “knowledge of the BMP attributes” and “implementation knowledge” (from “field days” hosted by extension specialists) reached a high enough level to stimulate a sudden and rapid fall in the “perception of risk and uncertainty”. The subsequent plugging of the motivation drainage flow stimulated the next period of rapid growth in “motivation” between months 30 and 50.

In month 54, “motivation” reached the tipping point and “on-farm testing” was stimulated. In between month 60 and 100, however, the growth in the “motivation” stock slowed down again. Steadily increasing “scale of on-farm testing” and a simultaneous slowing down of growth in the “motivation” stock is counterintuitive. This was the period when the “knowledge of attributes” stock also reached a maximum. It was mimicking the point when a farmer had learnt all that he could from others about the innovation. Any remaining “perception of risk and uncertainty” was not due to lack of knowledge. Instead it was due to lack of experience with the innovation itself. Hence, the decline in “perceived risk and uncertainty” also slowed down in the between months 60 and 100. In this period, as was mathematically programmed into the

model, the “perception of risk and uncertainty” was reduced to 50% by the maximum accumulation in “knowledge stock 2”.

The stable and continued growth in “scale of on-farm testing” eventually stimulated increased opportunities for “experiential learning” and a more rapid accumulation of “implementation knowledge”. The subsequent experience gained from “on-farm testing” influenced another rapid decrease in the “perception of risk and uncertainty” in month 100. The reduction of the “perception of risk and uncertainty” plugs the drainage flow from the motivation stock further. Simultaneously, the effect of “realising real benefits” (from on-farm testing) is triggered. Hence the higher inflow and the drastically reduced drainage flow collectively stimulated the next burst of rapid growth in the “motivation” stock, all the while reinforcing the desire to expand on-farm testing. Attaining the maximum “scale of on-farm testing”, coincided with zero “perception of risk and uncertainty” and maximum knowledge levels which appear to be all the necessary ingredients to stop testing and start implementing across the entire farm.

The results for scenario 3 are presented in Figure 6.12. The “magnitude” and the “frequency” of all the activities to create “learning experiences” in scenario 2 were exactly the same for scenario 3. The only difference was that the proportion of effort was equally directed to relative advantage and attributes. Hence, not only is the extension strategy still aggressive, but it is now also labelled as being more focused. The model is attempting to mimic a purposeful mental effort to invest energy and activity towards the two different causal links in the model. For this reason, the “knowledge stocks 1 and 2” grow at exactly the same rate. The result is depicted in Figure 6.12. The systemic knock on effect is the simultaneous increase in “number of motivating experiences” and the decline in “perception of risk and uncertainty”. The net effect is the much quicker rise in the “motivation” stock level to the tipping point and a substantially earlier initiation of “on-farm testing” in month 24.

In Figure 6.12, the difference in the initial rapid and steep decline of the “perception of risk and uncertainty” variable and the less steep and less rapid decline, later, is noticeable. Despite a simplified representation of complex psychological learning, perception and motivation processes, the model appears to adequately capture and exhibit the real world phenomenon where increasing knowledge levels from “information acquisition” is relatively quicker and easier, but limiting, in comparison to “learning from doing”. The effort and risk to test on a

small scale on one's farm is greater, but so too is the benefit in terms of experience and knowledge gained (Leeuwis, 2004).

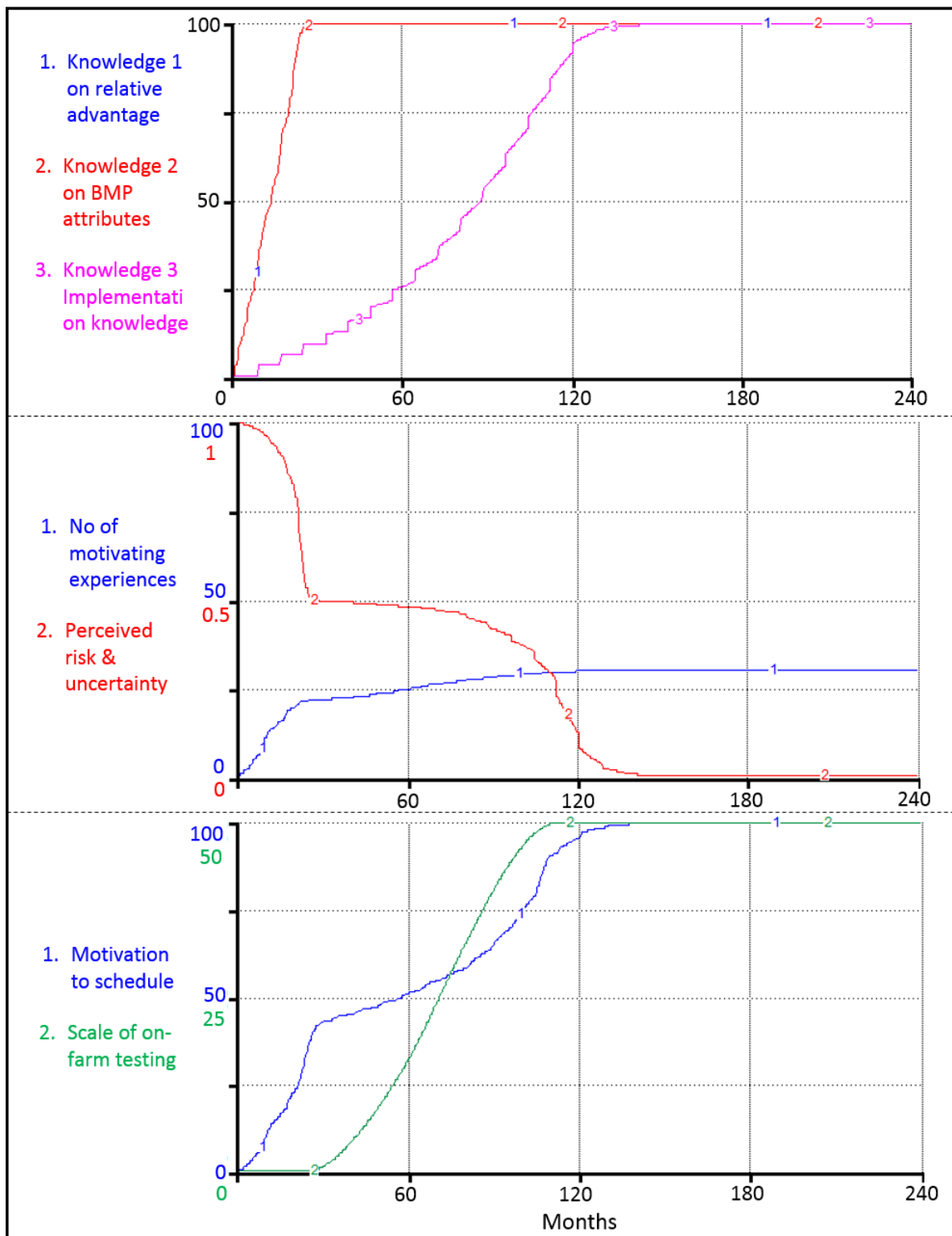


Figure 6.12 Simulation results for scenario 3 (A more aggressive and focused extension strategy)

The stock and flow diagram in conjunction with model simulation experiments helps to explain the dynamics of how on-farm testing can be triggered and incrementally increased in scale until full scale adoption. Reflecting on the structure of the stock flow diagram and the simulation results provides substantial insights. Possible reasons for non-adoption by an individual farmer, can include:

1. The presence of a “real risk and uncertainty” with the innovation. If the innovation is flawed, adoption of the product is considered a non-starter.
2. The poor “perception of relative advantage” due to low “knowledge levels of relative advantage”, i.e. when information from economic analysis is not available or not being made accessible to the farmers.
3. High “perception of risk and uncertainty”. Due to low levels of “knowledge of the innovation and its attributes”, in the first instance.
4. Sustained “perception of risk and uncertainty”. When “learning experiences” are limited to “information acquisition” from external sources, i.e. a lack of opportunities for farmers to gain personal experience with the innovation.

The reader is reminded, however, to be cautious of believing that a single intervention or pathway will help to achieve the goal. The model is merely a simplified representation of the interlocking web of cause and effect relationships and feedback structures in the real world. It is more likely that a combination of variables must be tuned, in correct proportions, for the correct duration of time, and informed by skilful tracking of feedback from the real world in order to achieve the desired goal.

6.3 Flaws, weaknesses and the simultaneous value of the on-farm testing model

The contention between limiting the model boundary and comprehensive capturing of influential variables once again surfaces. For example, it can be argued that relative advantage, a predominantly economic variable, is not the only way to motivate a farmer. Non-economic pathways also exist. Rock (2008), for example, points out that the promise of elevating social status or generating higher sense of control (autonomy) can also motivate an individual enough, to act. Hence, the system dynamics model is not comprehensive in representing all the pathways for increasing motivation. Nevertheless, relative advantage is an important pathway, supported by both literature and the narrative data, and was considered adequate for depicting the larger

systemic causal structure to trigger on-farm testing. Expanding the model boundary to include alternate paths for stimulating motivation, would have resulted in unnecessary complexity, without altering the behaviour mode of the model.

A second flaw is the simplistic paradigm that initiating on-farm testing in the model will automatically lead to increasing the “scale of on-farm testing”. On-farm testing failure or opportunity for failure has not been incorporated in the model. The absence of this aspect in the model was not due to perceived lack of importance. The author was simply of the opinion that there was a lot to learn from the current simplified paradigm. Expansion of the model to incorporate the possibility of on-farm testing failure, would have increased the number of variables and overall complexity of the diagram (model causal structure), which was expected to undesirably dilute the learning. The object of model construction was to understand and explore how on-farm testing is triggered, not how on-farm testing failure occurs. Hence, the incremental step taken in this study, in model construction and learning was considered pragmatic, with the knowledge and acceptance that on-farm testing failure is possible and can be later incorporated into future research.

The third weakness also exists in the mathematical representation of certain variables and relationships. For example, the tipping point value for the stock of “motivation” to trigger on-farm testing was assumed to be 40 %. Intuitively, it seems plausible that an accumulation of “motivation” to the 40 % level should be enough to stimulate a human being to act. But there is no data to support such an assumption. Furthermore, the author has no background knowledge and was certainly not qualified to design or implement psychological experiments with farmers to detect or estimate the tipping point value in a more scientific manner. As previously stated, the experts suggested that it was better to include the assumptions and its causal impact transparently, than to omit the variable due to lack of data (Sterman, 1994).

The above examples of model flaws and weaknesses were also valuable in the sense that they provide the opportunity for scrutiny of the model parameters and simultaneous deep reflection of our understanding, assumptions and mental models of the real world. The appreciation for knowledge gaps and humility of our own knowledge levels can be increased. For example, an array of existing pathways was mapped out for creating learning experiences for farmers. These included “written media”, “grower days”, “study circles”, “one on one extension” and “field days”. Even though these pathways exist, information about the “magnitude” and past

“frequency” of events was relatively poor amongst SASRI extension and knowledge management personnel. There were no formal databases to document and benchmark the extension and knowledge exchange activities, leave alone assessment or analysis of such activities. On an even more subtle plane, determining what “proportion” of effort was growing which knowledge stock (“knowledge of relative advantage” versus “knowledge of BMP attributes”) is at the best intuitive and/or speculative. While this can be considered a weakness, since speculative inputs were used to simulate a base run in order to represent the current reality (reference mode). Speculating, however, provides a great opportunity to stimulate debate, reflection and deeper learning. In this process mental models are surfaced and become available for renewal. In a similar manner, planning simulation scenarios and modelling experiments also stimulates deeper thinking and interaction with the real world. Hence, the modelling platform now provides SASRI with an opportunity to more formally inspect and experiment with the “magnitude”, “frequency” and the “proportioning” of effort of the various learning pathways, both in the computer model and in the real world. In addition, the dynamic modelling platform can further allow for the SASRI team to experiment with the timing and duration of interventions. Proactive, purposeful and focused efforts can be implemented to explicitly target the different knowledge stocks.

Finally, the model structure provides a reference frame for thinking about and understanding signals and clues from the real world. For example, if an extension specialist has the model structure in the back of his mind when interacting with an individual farmer, it may be possible to listen with more attuned lenses of the mind, so as to detect the presence of doubt and uncertainty or “low perception of relative advantage”. The concept of listening with more attuned lenses of the mind can be viewed as an enhanced skill developed by the extension specialists. The combination of the enhanced skill and knowledge of the system dynamics model map (which guides what to listen for in this instance) can further enable the extension specialists to ask follow up questions to verify that the knowledge stocks are low, for example. The above scenario aims to demonstrate how exposure to such a system dynamics model can equip an individual with higher understanding of underlying system structure, so that they can engage and strategically work with the complexity in a more meaningful manner.

7. CONCLUSIONS AND RECOMMENDATIONS

Globally, research and development for irrigation scheduling has received substantial investment and support, and has enjoyed a fair amount of success. A number of tools varying in degrees of cost, skill required and accuracy are readily available for farmers to use. Adoption of irrigation scheduling, however, still remains far below expectations.

The irrigation literature, based on a fair amount of studies, provided a list of variables which are deemed to either promote or inhibit the adoption of irrigation scheduling. Few studies, however, report success in bringing about widespread adoption. The lack of adoption in the presence of these clear incentives and substantial investment and research success is confusing. Irrigation management is embedded in a complex agricultural system. There are a multitude of factors which influence behaviour. The irrigation literature, however, seems only to list the factors which correlate with adoption behaviour. There is little evidence of studies which focus on complexities in the form of cause and effect relationships and feedback structures for irrigation management or irrigation scheduling adoption at the farm or field level.

A large component of the novelty in this project was attributed to engaging with the complexity via system dynamics modelling. The lack of dedicated literature suggests that, worldwide, nobody has used System Dynamics modelling to study the adoption of irrigation scheduling. System dynamics modelling is a technique for framing, describing, understanding and communicating complex problems or processes (Forrester, 1991).

The aim of the project was to apply system dynamics modelling to assimilate the socio-technical factors that impact on the spread of innovations, so that recommendations for improving adoption of irrigation scheduling can be made. On the basis of grounded theory, the system dynamics simulation platform provided a virtual world in which to conceptualise, test and visualise (or communicate) theories and hypothesis of how adoption might occur. The overarching theory, formulated in this thesis, is as follows. When an innovation first arrives in a community, there are no existing adopters and therefore no word of mouth within the community. Hence, early adopters tend to lean towards testing and experiencing for themselves in order to make the adoption decision.

If the on-farm testing process is successful, the early adopters will share the idea and their success with other farmers (through word of mouth). Some farmers will take heed of the information but will still not have enough confidence to adopt. These farmers having accumulated some information, via word of mouth, still have the need to test the innovation on their own farms before adopting. The early adopters, therefore, make use of both the word of mouth and on-farm testing mechanisms simultaneously. The remainder of the population (the majority of farmers) are not so keen to go through the pain of on-farm testing, and prefer to wait and watch how others fare. At this stage the balance between positive word of mouth and negative word of mouth will dictate if an innovation is a success or failure. The majority of farmers will make the adoption decision based on the strength and direction of ‘word of mouth’ signals from peers in the community.

The two system dynamics models were developed to capture and explore independently each of these facets, word of mouth and on-farm testing. It appears that the big opportunities to stimulate widespread adoption exists, firstly, in maximising the number of farmers who test the innovation on their own farms, and, secondly, in supporting the early adopters enough to ensure that they do not dis-adopt and give rise to negative word of mouth.

The word of mouth model was presented in Chapter 5. One of the main outcomes of the word of mouth model was that when an innovation was new and the number of existing adopters was low, dis-adoption and the subsequent negative word of mouth was innately a stronger force in comparison to positive word of mouth. Extension support to eliminate dis-adoption proved to be key in this early phase.

The word of mouth model also proved useful to demonstrate the connectivity and dynamic nature of the complex system. The stock and flow chain structure dictated that any change in one stock necessarily propagated a change in other stocks. For example, an outflow from the “aware farmers” stock had to result in an inflow in the “interested farmers” stock. An outflow from the “interested farmers” stock had to result in an inflow to the “adopter stock” or the “uninterested farmers” stock. An increase in the “adopters” increased “positive word of mouth”, while an increase in the “uninterested farmers” increased “negative word of mouth”. In this way, alternative outcomes of adoption success and failure was demonstrated via a shifting in the balance of forces over a period of time.

In the search for solutions, there is always a danger of looking for the most influential variable or lever, so that it can be activated to solve the problem. A common past mistake in adoption studies was to mentally assign or mentally assume a fixed and absolute strength to a variable over all periods of time (Sterman, 1994). In this way, the perceived important variable was mentally assigned high importance and became the focus of the improvement efforts. In the word of mouth model, variables such as “failure” by existing adopters, for example, was represented by a non-linear graphical relationship. In the graphical relationship, the variable in question is connected to some other variable in the system. In this case, “failure” was related to the number of existing “adopters”. Such a relationship transparently displayed that the strength of a variable was dynamic, i.e. different at different points in time, depending on the state of the system at that point in time. The implication was that the strength and/or direction of forces were not always static, nor do they work in isolation. Variables perceived to be important are typically embedded in a web of relationships making for difficult mental simulation of the strength or influence.

Similarly, if the underlying structure of the complex system is not comprehended, there is a danger of collecting real world signals and clues from a confined portion of the system and mentally projecting incorrect outcomes. A simulation experiment for the word of mouth model, exhibited this phenomenon of counterintuitive behaviour. In a model simulation scenario, adoption success was attained, but the number of “disgruntled- and uninterested-farmers” also increased simultaneously, despite an input of more extension support. In the real world, if an extension specialist was only exposed to signals from the “disgruntled and uninterested farmers”, and the signals (in the form of “negative word of mouth” and increasing number of “disgruntled farmers”) were getting louder, the extension specialist may very well be tempted to reduce or stop his support for an innovation, wrongfully believing that the innovation will not be adopted by the larger community. Complex systems can be deceptive.

The word of mouth model was also able to display that the magnitude and duration of an intervention does not necessarily translate linearly in to results. When adoption success occurred, the “adoption” stock exhibited the s-shaped growth curve, i.e. compounding growth followed by goal seeking growth towards saturation. In the compound growth segment, the “adopter” farmer stock initially takes a long time to grow. Few adopters in the early phase implies weak positive word of mouth and slow adoption rates. However, a turning point is reached and the growth suddenly becomes steep and rapid. A critical mass is reached when the

number of “adopters” generate enough positive word of mouth to stimulate accelerated growth. The principle of a compound growth curve, is that large growth takes place in a short space of time when the turning point (in this case, the critical mass of adopter farmers) is attained. The implication is that in the real world, extension specialists may have to work hard supporting innovations for longer periods of time, realising very little visible results initially, with the understanding that rapid adoption will only take place once a critical mass was available to adequately intensify positive word of mouth.

The on-farm testing model, presented in Chapter 6, offered a different set of insights. Promoting the benefits of irrigation scheduling in economic terms appeared to be a clear and obvious pathway for increasing the internal motivation of early adopters to initiate on-farm testing. Evidence from SASRI’s past popular press media depicted that not enough attention was given to actually reporting the cost and benefits of irrigation scheduling. Promoting benefits, however, is only one structural entry point in the system. If effort and resources were poured into mastering only this aspect, other forces in the system may get neglected. These other forces can easily override the effect of better promoting the benefit for irrigation scheduling. In the system dynamics model, the “perception of risk and uncertainty” drained the “motivation” stock, overriding any effort to increase motivation. The “perception of risk and uncertainty” was assumed to be high, when knowledge levels of the innovation and its characteristics were low, i.e. a farmer was expected to become less doubtful of an innovation only when he became more knowledgeable on attributes such as ease of use, technical soundness and practicality. The model structure revealed that it was necessary to increase motivation by promoting the relative advantage, while simultaneously limiting the outflow of motivation by reducing “perception of risk and uncertainty”. “Learning experiences” via “acquiring information” from others, however, was never enough to totally eliminate the “perception of risk and uncertainty”. Nevertheless, adoption could take place when there was still some doubt and uncertainty in the minds of the farmer. When the early adopter type farmer accumulated enough “motivation”, “on-farm testing” was initiated to learn more about the innovation. It was necessary for the farmer to gain direct personal experiences with implementing the innovation. “Learning by doing” allows for the accumulation of knowledge on the real benefits. Furthermore, practical experience helps the early adopter farmer to incrementally eliminate the “perception of risk and uncertainty” such that the “scale of on-farm testing” is increased, until the farmer is convinced and decides to implement the innovation across the whole farm.

The reader is reminded that, in the literature review in Chapter 2, the work of past authors was tabulated in Table 2.2 to establish the levels of agreement on important variables which were deemed to influence adoption of irrigation scheduling. Of the list presented, 81 % of the authors cited that training and support was an important factor. Economics and attributes of irrigation scheduling were also considered important by 62 % and 52 % of the authors, respectively. Therefore, it is not a surprise that “extension support”, “relative advantage” and reducing “perception of risk and uncertainty” by growing “knowledge of the innovation attributes” feature strongly in the system dynamics models. The historical poor adoption of irrigation scheduling was not necessarily because of poor understanding of what factors are influential. Instead it is more likely to be the inability to engage with the complex system in a more meaningful manner. The iceberg analogy (Section 3.3, Figure 3.4, page 33) was used to help the reader to appreciate that the less visible, difficult to quantify and novel variable “motivation” was introduced into the system dynamics model structure in order to define and demonstrate the causal direction and connectivity of the abovementioned better known variables. In this way, the work reported in this thesis was considered to contribute to advancing the field of study by extending beyond just listing key variables as important. Instead, resultant behaviour modes were demonstrated to be the effect of a number of causal relationships working together as a collective system.

The conceptually linked ‘word of mouth model’ and the ‘on-farm testing model’, as depicted in Figure 6.1 helps to further demonstrate that silver bullet (single pronged) solutions with over-emphasis on a single variable is not the answer. The developed simulation platform provides opportunities for virtual testing of a range of intervention combinations. In addition, the timing and duration of interventions, and a number of permutations, can also be experimented with. From this modelling work, however, one should not aim to derive a recipe or formula with which to increase the adoption of an innovation across a community. The reader should recognise that the world is a complex and dynamic web of relationships. For this reason the recommended way forward is ongoing real world implementation experiments with a suite of interventions, informed by the causal pathways and simulation experiments of both models, but taking care to continuously account and correct for signals and feedback from the real world.

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9. APPENDIX 1 – MODEL MAPS

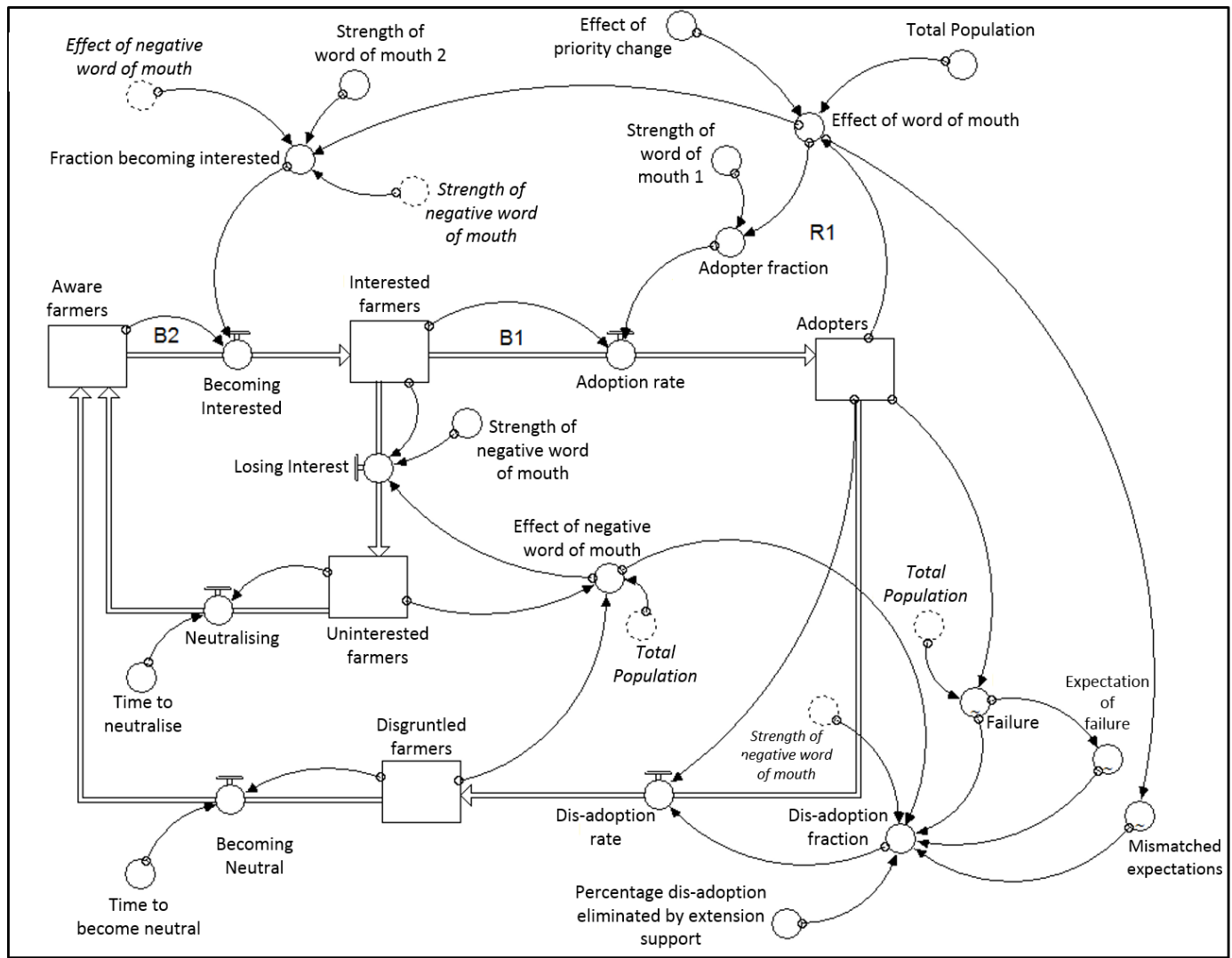


Figure 9.1 Word of mouth model map

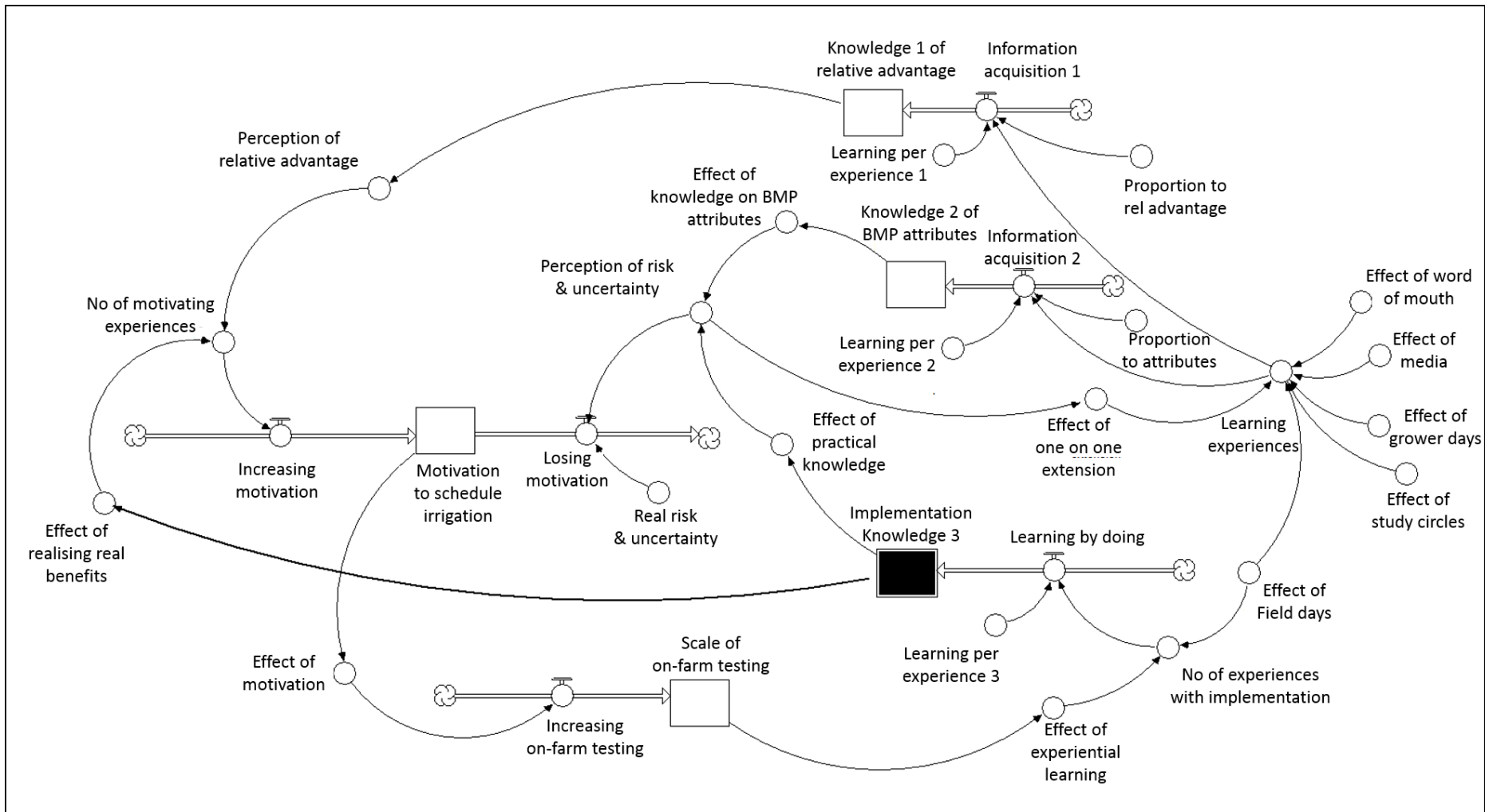


Figure 9.2 On-farm testing model map

