THE DEVELOPMENT OF A SINGLE STRATEGY FOR THE INTEGRATION OF QUANTITATIVE AND QUALITATIVE DATA TYPES FOR THE PRODUCTION OF DECISION SUPPORT SYSTEMS

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ABSTRACT

The research described in this thesis expresses the importance of quantitative and qualitative data types and how these can be incorporated and combined to produce an agricultural management decision support system (DSS). Researchers cannot solely depend on numerical data and relationships when designing, modelling and producing decision management tools. The relevance of the social sciences and peoples interpretations of these tools is equally important.

The DSS described here focuses on the management of rainwater harvesting (RWH) in Tanzania. Numerical data related to natural resources (water and nutrients) and yields of rice and maize have been collected for the production of the DSS. With regard to the social science factors, the DSS tackles the concept of common pool resources (CPR) of water and nutrients. The importance of CPR is well understood, however their inclusion in the production of models is a relatively new concept. Criteria related to social status is linked with the by laws that govern the allocation of natural resources in Tanzania to help derive a numerical method for including CPR within the DSS. The production of the DSS is a novel way of combining this research into a tool that aims to benefit all socio-economic community groups.

During the production of the DSS, a single generic approach for the inclusion of quantitative and qualitative information has developed. Particular focus was on the development of a *model base* (programming and mathematical relationship building), *database* (storage of the data used for the relationships) and a *dialog system* (the user-interface and communication strategy). This method is termed the ‘dialog, data, and models (DDM)’ paradigm (Sprague and Carlson, 1982).

From this research, a DSS has been produced that aims to optimise RWH management in Tanzania with the aim of alleviating poverty and enhancing sustainable agriculture for all community members. Also an overall strategy for the production of DSSs has been produced. It illustrates how both quantitative (numerical and physical data) and qualitative (socio-economic considerations) can be utilised individually and in combination for the production of DSSs and can be extrapolated for further research and to new areas.

CONTENTS **PAGE**

Chapter Seven: DISCUSSION

LIST OF TABLES, FIGURES AND PLATES **PAGE**

Chapter Three: 104

Chapter Four: **148**

Chapter Five: 198

GLOSSARY

- ATLAS/TI – Archiv fuer Technik, Lekenswelt und Alltagsspreche. (archive for "technology", the life world and every day language / text interpretation)
- CA – Catchment area
- CAD – Computer aided design
- CAQDAS – Computer assisted qualitative data analysis software
- CB – Cropped area
- CPR – Common pool resource
- CWR – Common water resource
- DBMS – Database management system
- DDM – Dialog, data and models paradigm
- DGMS – Dialog generation management system
- DSS – Decisions Support System
- ET - Evapotranspiration
- GIS – Geographical information systems
- HH – Household
- MASL – Metres above sea level
- MBMS – Model base management system
- MIS – Management information system
- MS – Microsoft
- NGO – Non-governmental organisation
- NUD*IST – Non-numerical Unstructured Data Indexing, Searching and Theorizing
- PARCHED-THIRST – Predicting arable resource capture in hostile environments during the harvesting of incident rainfall in semi-arid tropics
- PRA – Participatory rural appraisal
- PT – Parched-Thirst
- RWH – Rainwater harvesting
- SF – Single field
- SHARES – Shared Resource
- SUA – Sokoine University of Agriculture
- SWEAT – Soil, water, energy and transpiration

- TAS – Tanzanian shilling
- TCRU – Tropical crops research unit
- TLU – Tropical livestock unit
- UAT – User acceptance testing
- URT – United Republic of Tanzania
- VB – Visual basic
- WPLL – Western Pare Lowlands

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"Your song you sing it into me, my hope you breathe in me"

(Neilson Hubbard, 2003).

Cheers!

Chapter One

INTRODUCTION

1.0 Objectives and Aims of the Study

This study aims to look at the ways that quantitative and qualitative information can be integrated for the production of decision supports systems (DSS). Numerical data (quantitative information) is considered alongside that of human perceptions and the influence of socio-economic factors (qualitative information) on the decision-making process.

This study has two objectives. (1) To develop a DSS that incorporates quantitative and qualitative data to aid in the management of rainwater harvesting (RWH) in Tanzania to help enhance sustainability of livelihoods of the farmers, and (2) To outline where experience gained in the development of the Tanzanian DSS might contribute to a generic strategy/approach for the development of DSSs.

Much of the scientific literature states how DSS's tend only to utilise either qualitative or quantitative data sources (Marshland *et al,* 2001). Moulin (1994) describes how DSSs can be classified into two categories. The first consists of models based on production functions calculated with empirical or mechanistic relationships between properties. This category of DSS focuses on numerical data that have been collected and analysed quantitatively. The second category includes those based on rules derived from expert knowledge and focus upon potential social constraints that may influence management options (Wagner, 1993). The second category utilises collection and analysis methods derived qualitatively.

Parker *et al* (1997) and Marshland *et al* (2001) express the importance of being able to combine both quantitative and qualitative information to enhance the development of DSSs as well as enhance their uptake in the field. This study aims to build on research in the field of DSS development by taking the two categories of DSS and developing a strategy to link their functionality. This will in turn lead to the production of a novel and single systems development lifecycle for the production of management DSSs. Marakas (2002 and 2003), describes numerous strategies for the development of DSSs. He explains that there is no definitive strategy as they each share similar attributes. This study aims to combine these attributes.

Scientists nowadays need to be able to embrace both the theoretical and social aspects of the science that they study. The reason being is that this will help to add structure and validity to any research outcomes that are derived. There is often scepticism behind numerical results, and being able to back up findings with actual physical observations increases scientists' confidence in their findings, as well as increasing the reliability of the information for other interested parties (Bryman, 2004; Silverman, 2004). Researchers cannot solely depend on numerical data and relationships when designing, modelling and producing decision management tools. This approach to modelling decision management tools has often lead to failures in the uptake of the systems (Matthews, 2002; Marakas, 2003) as the end users of the tools have not been considered. The relevance of the social sciences and peoples interpretations of these tools is becoming more important to the scientists designing the tools, as this helps to enhance the uptake and understanding of the tools by the potential end users (Marakas, 2003, Bryman, 2004). Hence methodologies and sound examples of how both of these aspects can be combined, to form a single tool, will help to enhance our understanding and development of DSSs. Also, by incorporating qualitative studies it has been observed that the scope for which DSSs can be applied can be increased (Hampson, 2000; Matthews, 2002).

This thesis, describes a specific study where physical, biological and social sciences are combined for the management of rainwater harvesting (RWH) in Tanzania. The aim of the study is to show how a DSS can be used for better allocation of rainwater, for farmers in Tanzania. The focus being to help enhance the sustainability of livelihoods of farmers in the field.

The importance of being able to maintain the sustainability of the livelihoods of the different types of farmers in Tanzania is that with projected population increases, primarily in the developing countries (like Tanzania) (FAO Statistics, 2001, 2005), there will ultimately be strain placed on farmers and farming practices to ensure they can meet the demand for extra food. On a global scale, it has been predicted (FAO

Statistics, 2001, 2005) that by 2020 the world's farmers will need to produce 20% more grain to meet the increase in demand. This increase in population will also have knock-on effects on the levels and utilisation of natural resources. In Tanzania the fundamental resource is that of water, and therefore management approaches to the utilisation and distribution of water amongst all farmers need to be developed and improved. These improvements to water management will help sustainable agriculture in Tanzania (Hatibu, 2002).

Arable agriculture is a major way in which people interact with the natural resource base in developing countries (Matthews and Stephens, 2002). In Tanzania the majority of farmers grow either maize or rice. These are staple crops and are essential for the maintenance of the farmer's livelihoods. The farmers require access to water and nutrients (through manure) to help enhance the production of their crops. However it has been observed that if the cropping systems in place are sub-optimal or inappropriate, then the farmers are likely to not benefit from the natural resources that they have access to (Kajiru, personal communication, 2002; Hatibu, 2004). It is important that the management techniques that are put in place to help improve the interactions between arable agriculture and natural resources are beneficial (and successful) for the farmers (Matthews, 2002).

Traditional agronomic research has made remarkable advances in recent years in improving some of these agricultural practices. Examples include RWH methods, improvements to irrigation systems and improved crop selection and management (Hatibu *et al*, 2000). In addition to conventional methods of field research, the recent introduction of computer models has led to the recommendation of improved management practices (Boote *et al*, 1996; Matthews and Stephens, 2002; Young *et al*, 2002). In some cases, crop and soil simulation models (Baker, 1996; Matthews and Stephens, 2002) are being developed with the capacity to integrate research from many different disciplines and locations. These provide an opportunity to improve the efficiency and/or reduce the cost of conventional research while still providing realistic management options.

This study represents the 'building blocks' of something much larger, an area of systems analysis and DSS development that until recently scientists had only scratched the surface of. Scientists now possess the tools, methods and ability to manipulate and exploit both the theoretical and social aspects of science, and apply these to the improved production of management DSSs.

1.1 Thesis Structure

Chapter One of this thesis states the aims and objectives. Subsequent chapters focus on specific aspects of the methods and study area.

Chapter Two focuses on the study region and why it was chosen. The importance of the study will be expressed in relation to the different socio-economic groups in Tanzania and their particular agrarian constraints. A detailed description of Tanzania and the particular study sites is developed to provide the context for the development of the DSS. The study sites being Maswa and the Western Pare Lowlands (WPLL). Environmental, topographical and infrastructural traits will be outlined via the use of maps and figures. The concept of RWH will be discussed in detail as it is a fundamental aspect of the DSS that is being produced. The agrarian constraints faced by the farmers in Tanzania will be outlined with reference to how the DSS will help to overcome these. The historical context of the study shall be detailed. For example the role of the team working in Nottingham was a small part of a longer term project initiated and managed from Tanzania.

Chapter Three details the various types of system development cycles that were considered as a basis for this sort of research. The importance of each type is expressed. The thesis then highlights how these methods can be combined to help produce a single coherent DSS development process flow that incorporates both quantitative and qualitative data from the study sites in Tanzania. Also the communication strategy between the team working in Tanzania and the group in Nottingham are expressed and limitations and benefits discussed.

Chapter Four discusses the types of information – quantitative and qualitative – that are required for the development of the DSS. The chapter also considers approaches to data capture and manipulation in an integrated approach that incorporates both methods to form a single output. Data capture for this project is of particular importance. This chapter will discuss the approach adopted for producing the Tanzanian DSS and state any limitation and advantages to the methods described.

Chapter Five gives details of the products developed within this study and their application. Conclusions are drawn for each system that has been developed. The chapter explains how the data provided by the researchers in Tanzania have been utilised for the production of the DSS. Model development and validation are discussed with particular focus on the participants in Tanzania. The design of the system is highlighted. Example runs of the DSS are illustrated and discussed.

Chapter Six describes the full process for using the developed DSS and its subsidiary products. A step-by-step guide both for the development of the DSS for Tanzania, and the application of the DSS in Tanzania will be expressed. These guides aim to be coherent so that someone taking this research to the next level can follow the processes easily. Each aspect of the process guides are discussed in relation to the Tanzanian study, stating benefits and limitations of the approaches. Particular interest and focus will be on the potential users of the systems and how these people will interact with the beneficiaries of the products produced during this research.

Chapter Seven draws upon the information in the preceding chapters to derive conclusions based upon this study and its final outcomes. The importance of the findings will be stated, the underlying methodologies reiterated and the potential future scope of this field of study expanded.

Chapter Two

THE STUDY: Tanzania and the concept of Rainwater Harvesting

The objective of this chapter is to outline the historical context of this research and to discuss its importance in relation to the development of improved management systems in Tanzania. When designing and developing any form of management system it is essential that the researcher has a good understanding and links with the study region, the participants (both additional researchers and end beneficiaries) in the research, and knowledge of proposed end solutions (Matthews *et al*, 2002). This will enhance the uptake of any newly proposed systems or approaches.

2.0 Historical Context

Since 1991, the Faculty of Agriculture of Sokoine University of Agriculture (SUA) in Tanzania has been implementing a research programme on soil-water management. The main purpose of the programme was to develop, test and provide appropriate and socio-economically viable management interventions for optimising the capture and utilisation of rainfall – e.g. Rainwater Harvesting "RWH" in semi-arid areas of Tanzania (Mahoo *et al*, 1999; Mzirai and Kajiru, Personal Communication, 2003).

After a decade of field-based activities, it became apparent that there was a need to develop support systems to assist extension staff and others to plan, design and implement RWH systems. It was agreed that the use of computers could assist in the development and promotion of effective approaches to RWH by quantitatively integrating water and nutrient issues at the farm level.

2.1 Link between Nottingham University and Tanzania

There are strong links between Nottingham University and the research team working in Tanzania. It is these links that brought about this study and the strong relationships between both parties has ensured the progression and application of this research.

It was through discussions with our collaborating partners in Tanzania that the idea of producing a DSS was identified as an approach for tackling the issue of RWH management in Tanzania.

From the standpoint of the Tanzanian team, the objectives of this study were to:

1. Produce a DSS that can be implemented at the village level by trained extension specialists. Table 2.1 gives details of the administrative levels and the potential approaches to modelling that could be applied.

Administrative Level	**Hydrological System**	**Type of Modelling Intervention**
District	Sub-basin	Macro PARCH
Ward	Catchments	Micro PARCH
Village	Watershed	Delphi and PARCH
Sub-village	Landscape	Data matrix
Farm	Unit	

Table 2.1: **Types of Modelling Intervention.** Information specified by Tanzanian team (Hatibu, Personal Communication, 2002).

The DSS will be the final system that encompasses the modelling aspect, while the model will be the tool used for manipulating the inputs and obtaining the outputs that will be displayed by the DSS. The modelling approach provides the mechanics behind the DSS.

2. Allow extrapolation from where data are collected (village, catchment) to the district (study region) and the system (semi-arid tropics)

From Nottingham University's standpoint the objective was to help improve the management of RWH systems in two districts of Tanzania. The decision was made to design and implement a DSS that can be accessed by extension officers for the benefit of both individual farmers and communities. It was envisaged that the DSS would build on past research on RWH management and previous models developed by the Sokoine group and its collaborators.

The aim was to initiate a new form of model/tool that is simple yet robust based on a quantitative evaluation of physical (in particular water and nutrients), human (community activities), and biological (crop resource capture and use) resources.

Nottingham University researchers were to contribute the production of the DSS through sound analysis of data provided by the team in Tanzania, and the utilisation of extensive studies already carried out at Sokoine University into the field of RWH.

Alongside the development of the DSS using actual physical data, Nottingham University has instigated a novel addition to the DSS by integrating social factors that influence the management of RWH. Decision support tools currently in use tend to only focus on either numerical or social data (Goudriaan, 1994; Moulin, 1994; de Kok and Wind, 2003), few integrate both forms. It was the aim of this study to integrate the two aspects. The need for this was obtained through discussions with partners in Tanzania and the sharing of extensive community based information that influences the allocation and partitioning of natural resources in semi-arid areas of Tanzania.

The implementation of a DSS that tackles RWH management in Tanzania is the focal point of this study. A profile of Tanzania, detailing topographical, climatic and agricultural information associated to the country shall now be presented.

2.2 Research Context

In many parts of Tanzania, rainfall exceeds potential evapotranspiration in only a few scattered days. The growing season is short and significant dry spells occur frequently (Mahoo *et al.,* 1999). In contrast, there are districts in the country where the long term average rainfall is more than 1000mm yet crop production is low. This is a result of poor distribution of rainfall which leads to water stress on plants during one or more stages of crop growth (Mahoo *et al.,* 1999; Hatibu *et al.,* 1999; Gowing *et al.,* 1999). Therefore, the plants may use all the rainwater but yields would be low especially if the water stress occurred at a critical growth stage such as tassling in maize. There is a fair overlap between semi-arid areas and poverty in Tanzania and one way to reduce poverty is to harvest and use rainwater more efficiently for crop production.

This leads to the concept of rainwater harvesting and its current practice in Tanzania. This shall now be discussed.

2.3 An Introduction to Rainwater Harvesting

The practice of having lowland fields situated a long way from homesteads, locally known as *Mashamba ya Mbugani,* is a good starting point in conceptualising the meaning of rainwater harvesting. The farmers grow water demanding crops such as vegetables, rice and maize in the lower parts of the landscape. In this way, the farmers exploit the concentration of rainwater and nutrients flowing into the valley bottoms from surrounding high grounds in the landscape (Rwehumbiza *et al.,* 1999).

Therefore, from a crop production point of view, RWH involves the process of concentrating rainwater from a large land area into a small area so as to improve soil-moisture status in the smaller area. This definition is limited however, as it only deals with the spatial nature of the intervention. In practice, this will not be adequate as the rainfall is not evenly distributed in time. To overcome the problem of poor temporal distribution, it is necessary to collect rainwater and store it for use to meet water needs in subsequent dry periods.

Outlined below are some charts (Figures 2.1 and 2.2) taken from an article by Mahoo *et al* (1999) that illustrates the variability in rainfall in Tanzania and how this might affect the transferability of experimental results for the development of the DSS. Rainfall in the semi-arid areas of Tanzania is variable with respect to both time and space. Therefore it should be considered when developing any form of system that is designed for the management of water.

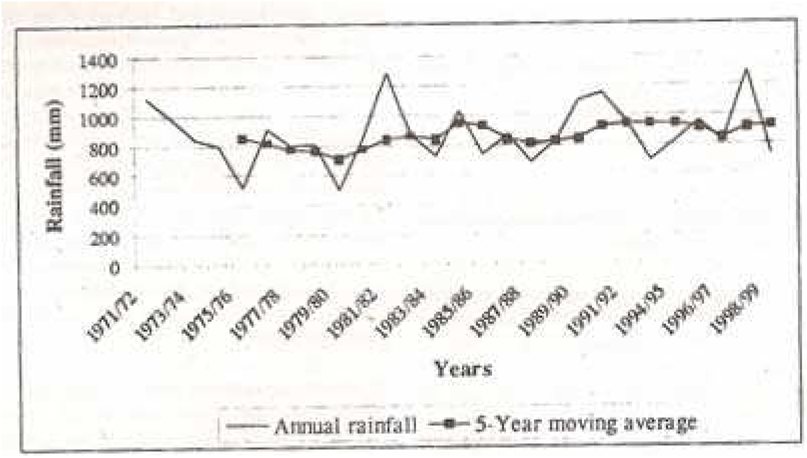


Figure 2.1: An example of rainfall variation in the district of Maswa in Tanzania. (Mahoo *et al*, 1999)

Figure 2.1 above helps to illustrate how there is great variation in rainfall within the semi-arid regions of Tanzania over the 30 year period that data has been collected.

Figure 2.2 demonstrates comparisons between seasonal trends within different villages in Tanzania.

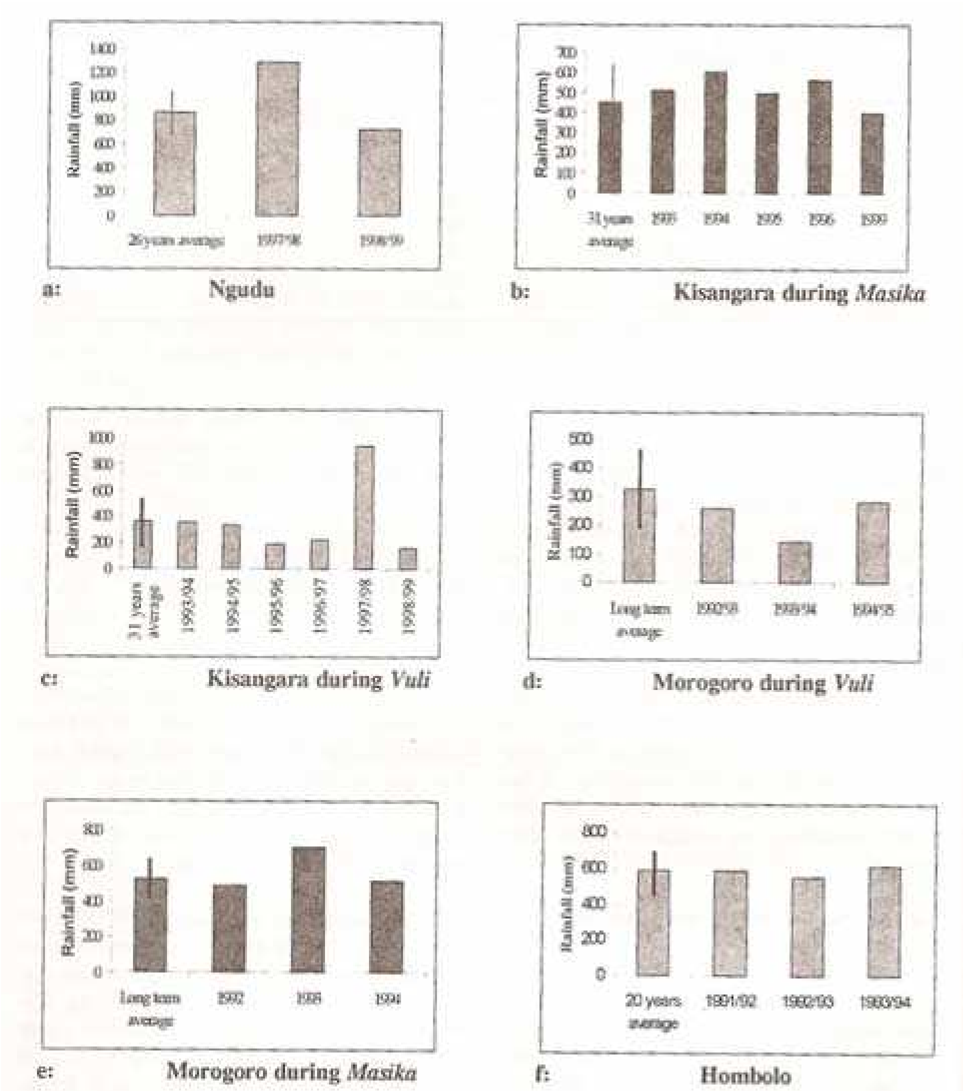


Figure 2.2: Comparisons of seasonal totals with long term averages for various villages in Tanzania. Adapted from Mahoo *et al* (1999).

The following graph (Figure 2.3) demonstrates the seasonal trends in rainfall for central regions in Tanzania. As illustrated, the months from December to May show the greatest increase in rainfall. It is within these months that crops should be started to be planted so they can make use of the available resource to ensure they establish themselves. During the months of less rainfall (September – October) harvesting should take place and this will be the period when labour is likely to be required. Weeding and other management approaches such as nutrient application should coincide with rainfall events, especially for nutrient application as water will help the mobility of the nutrients.

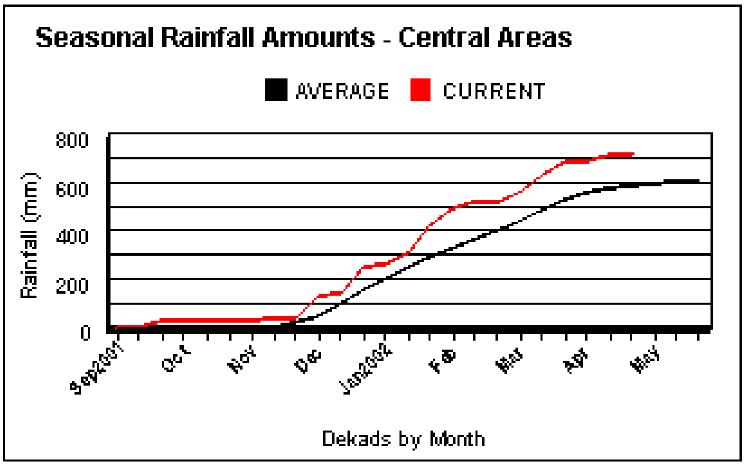


Figure 2.3: Seasonal rainfall amounts in Tanzania. Focus on the central areas. (www.africaguide.com/country/tanzania/info.htm)

Temperature comparisons should also be mentioned as these will have an influence on evaporation of any rainfall and will influence the availability of water for crops and RWH practices. The following graph (Figure 2.4) and diagrams (Figure 2.5) illustrate the variability in temperature in Tanzania. Temperatures in Tanzania remain fairly constant during the day however at night they can drop quite sharply (http://www.overlandingafrica.com/africa-weather.php).

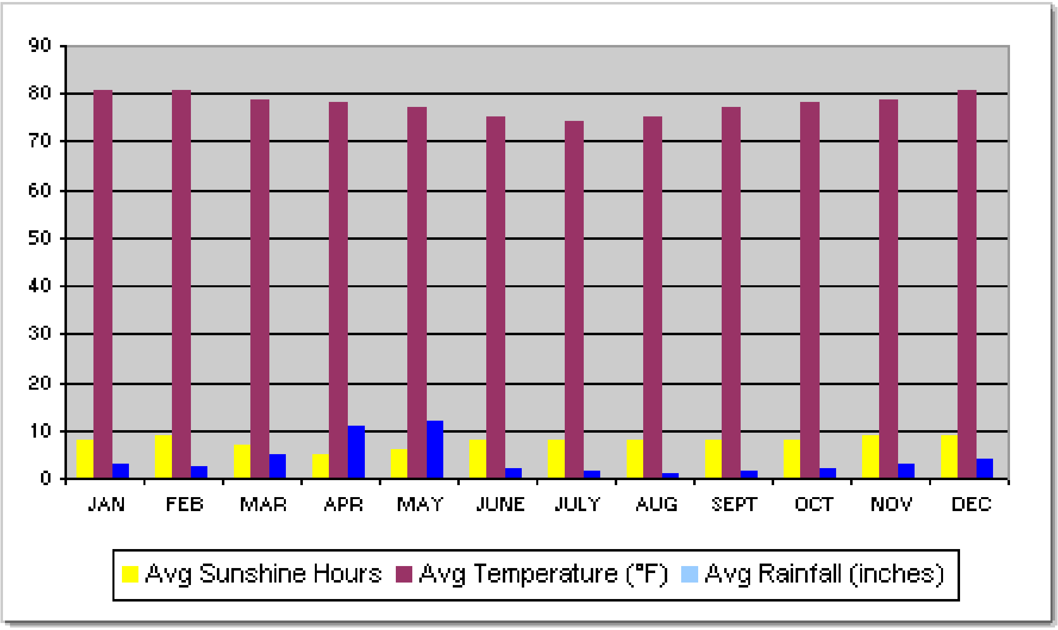
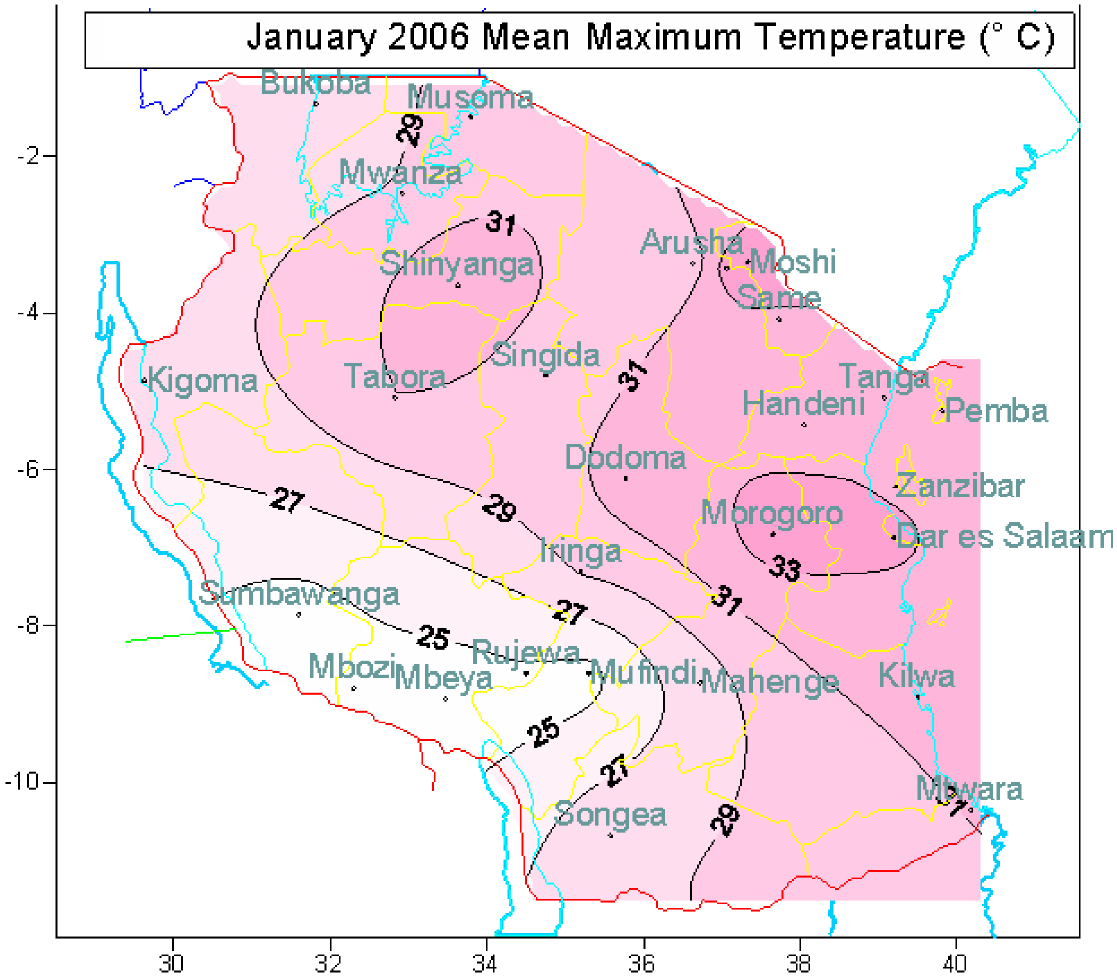
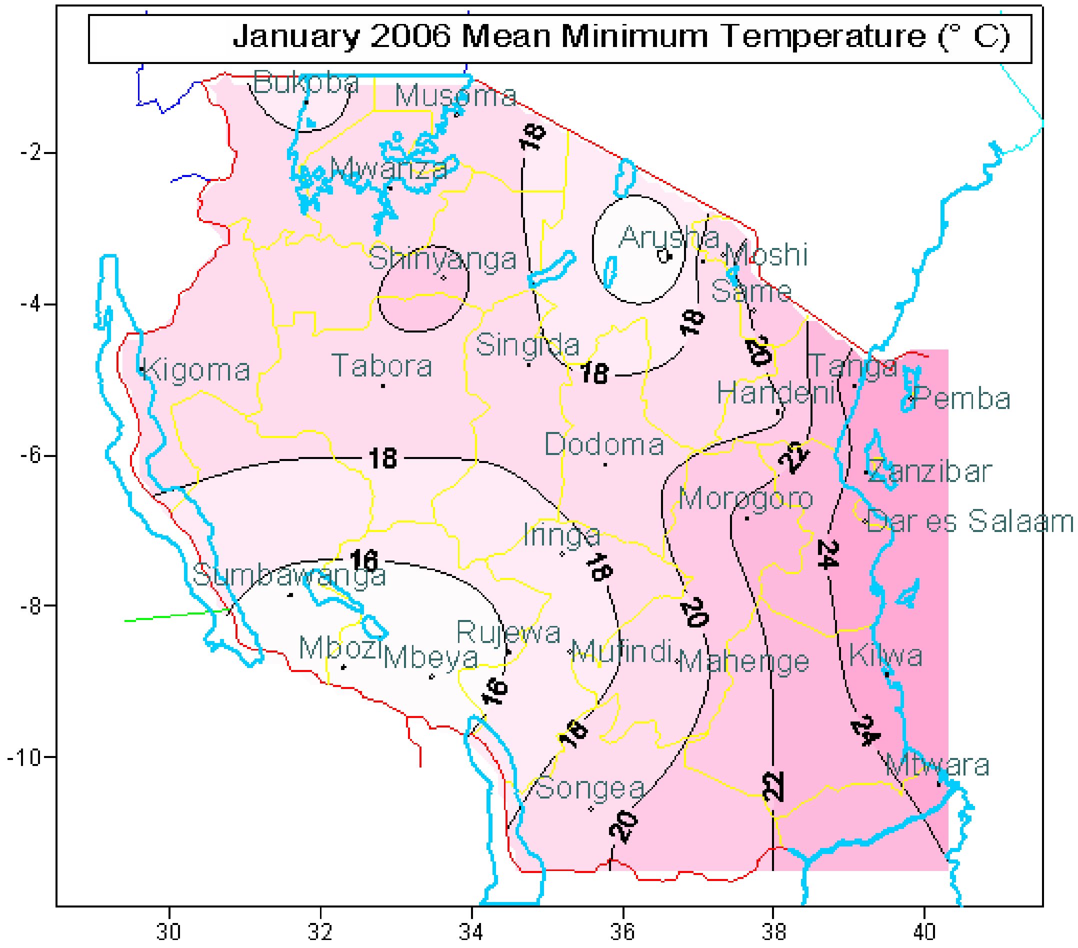


Figure 2.4: Comparison of seasonal temperatures and rainfall in Tanzania. (www.africaguide.com/country/tanzania/info.htm)



(a)



(b)

Figure 2.5: (a) Diagram demonstrating the mean maximum temperature across Tanzania. (b) Diagram demonstrating the mean minimum temperature across Tanzania. (http://ww.meteo.go.tz/bulletin/januarry06bulletin.htm)

The following screenshot tables taken from www.classicescapes.com illustrate rainfall (Figure 2.7) and temperature (Figure 2.6) information for different regions in Tanzania. The areas that are of interest with regard to this study are around Dar es Salaam, the base of Mount Kilimanjaro and Arusha.

Tanzania: Average Temperature (ºF) - Average lows and highs						
	Jan	Feb	Mar	Apr	May	June
Arusha	50/84	51/84	53/81	57/77	52/72	48/70
Dar Es Salaam	80/88	80/89	80/87	78/85	76/83	74/82
Mahale	68/81	68/81	67/81	67/80	67/80	65/79
Manyara (h)	82	84	84	79	77	73
Mt. Kilim. base	63/90	64/92	65/89	65/84	67/79	61/77
Ngorongoro (h)	68	70	70	64	63	59
Ruaha	56/77	59/77	58/77	59/76	57/75	53/73
Serengeti	81	82	82	77	75	71
Zanzibar	76/80	76/91	77/91	77/86	75/84	74/83
	July	Aug	Sep	Oct	Nov	Dec
Arusha	49/69	48/72	47/76	51/80	51/81	50/81
Dar Es Salaam	73/81	73/82	74/83	75/84	77/85	79/86
Mahale	63/82	65/80	68/81	69/81	68/79	67/79
Manyara (h)	70	66	73	79	79	82
Mt. Kilim. base	59/77	59/79	60/83	61/87	63/88	63/88
Ngorongoro (h)	55	52	59	64	64	68
Ruaha	53/74	53/74	54/77	56/81	58/82	59/79
Serengeti	68	64	71	77	77	81
Zanzibar	72/82	72/83	72/84	73/86	75/89	76/89

Figure 2.6: Average temperatures for different regions in Tanzania.

Tanzania: Average Rainfall (inches)						
	Jan	Feb	Mar	Apr	May	June
Arusha	2.6	3.0	6.3	14.0	7.1	1.3
Dar Es Salaam	2.8	2.5	5.0	10.6	7.2	1.3
Mahale	4.7	4.8	5.8	6.1	2.3	0.3
Manyara	0.5	0.4	0.3	0.9	0.5	0.1
Mt. Kilim. base	1.5	1.8	4.6	12.9	7.1	1.4
Ngorongoro	0.7	0.6	0.5	1.1	0.7	0.2
Ruaha	6.6	5.1	6.4	3.2	0.4	0.0
Selous	4.4	3.5	5.7	7.5	2.9	0.5
Serengeti	0.2	0.2	0.5	0.9	0.4	0.0
Zanzibar	3.0	2.4	5.9	13.8	9.9	2.1
	July	Aug	Sep	Oct	Nov	Dec
Arusha	0.6	0.7	0.7	1.4	4.9	3.9
Dar Es Salaam	1.1	1.0	1.1	1.9	3.3	3.7
Mahale	0.1	0.1	0.8	2.0	5.3	5.8
Manyara	0.1	0.1	0.1	0.2	0.6	0.7
Mt. Kilim. base	0.8	0.7	0.6	1.3	2.6	2.1
Ngorongoro	0.2	0.2	0.2	0.4	0.7	0.9
Ruaha	0.0	0.0	0.0	0.3	1.6	5.1
Selous	0.2	0.2	0.5	1.1	3.3	4.1
Serengeti	0.0	0.0	0.1	0.2	0.5	0.4
Zanzibar	1.7	1.5	1.9	3.4	7.9	5.7

Figure 2.7: Average rainfall in inches for the months of the year.

The information presented in figures 2.1 to 2.7 related to environmental conditions (temperature and rainfall) are helpful when it comes to planning agricultural management methods. Such as having a greater understanding of when crops should be planted based on whether there will be sufficient soil moisture to ensure crop establishment. Plus it also links in with the knowledge of when additional labour may be required for planting and harvesting procedures, as well as other agricultural management processes what may be required such as weeding. With regard to RWH, knowledge of rainfall data will help in understanding the potential levels of water resource that could be captured and utilised. This leads onto the definition of RWH.

In the broadest sense, RWH is defined as the process of concentrating, collecting and storing rainwater for different uses at a later time in the same area where the rain falls or in another area during the same or later time (Senkondo *et al,* 1999; Hatibu *et al,* 1999; Rwehumbiza *et al*, 1999). The harvested water can be used for many purposes, such as supplementary irrigation, domestic water supply and water for livestock.

RWH is justified by the nature of rainfall in semi-arid areas, where if not managed, the rainwater will quickly evaporate or run as flash floods into oceans and lakes, or damage infrastructure e.g. roads and railways. Consequently, it has been argued that the starting point of RWH is to capture rainwater where it falls for purposes of meeting water needs in that area. Any excess can then be transferred for use in downstream areas (Rwehumbiza *et al*, 1999). Hence, RWH for crop production is a continuum ranging from conventional soil and water conservation at one end to irrigation at the other.

Rainwater harvesting is an umbrella term (Bradley *et al*, 1996) that describes a range of techniques for collecting, concentrating and conserving water derived from rainfall runoff. Various attempts have been made to classify the different techniques of RWH according to the nature of the runoff process involved (Gowing *et al*, 1999). In general, classification is according to the size ratio and transfer distance between the runoff producing, (normally called the catchment area) and the runoff receiving area – the cropped basin. There are three main RWH categories:

- Micro-catchment or within field methods, which involve transfer of water over a short distance (0-50 cm) usually by sheet flow. These are sometimes referred to as ‘runoff farming’ systems.

- Macro-catchment or external catchment methods, which involve collection of water from a catchment area at a considerable distance from the receiving area and its transfer by channel flow. These are also referred to as ‘flood diversion’ or ‘external catchment’ systems.
- *In-situ* systems which are similar to conventional soil and water conservation practices.

RWH systems can be represented as a combination of runoff producing and runoff receiving areas. (Figure 2.8)

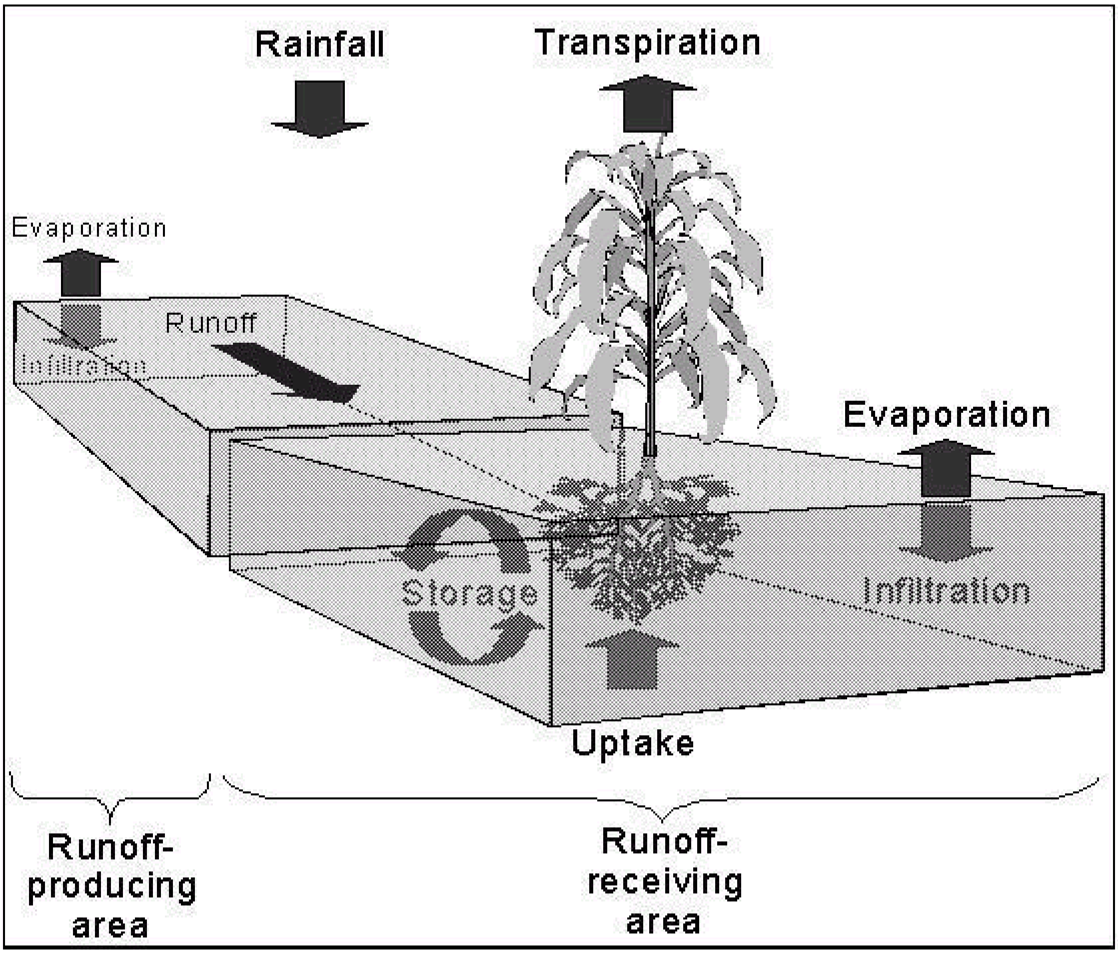


Figure 2.3: **<u>Illustration of RWH</u>**. Highlighting the concept of rainwater harvesting.

Outlined below are some examples of the main approaches to RWH, as adapted from Gowing *et al* (1999).

- *In-Situ* RWH

In-situ RWH, otherwise known as soil-water conservation, comprises a group of techniques for preventing runoff and promoting infiltration. The aim is to retain moisture that would otherwise be wasted as runoff from the cropped area. Rain is conserved where it falls, but no additional runoff is introduced from elsewhere (Gowing *et al.*, 1999).

This approach is appropriate where the main constraints are soil related, but rainfall is adequate. Water acceptance may be hindered by low rates of infiltration caused by surface crusting (capping). Alternatively, the problem may be attributable to low percolation rates caused by restrictive layers in the soil profile. These problems may be due to inherent soil characteristics or to previous management (e.g. formation of plough pan, compaction by trampling).

Specific techniques include:

1. Conservation Tillage

Conservation tillage is a generic term for the use of tillage techniques to promote *in-situ* moisture conservation. This can be achieved by creating micro-relief to increase retention storage (e.g. tied ridges), by breaking sub-surface pans and through deep cultivation (e.g. chisel ploughing), or by contour ridges.

2. Pitting

Planting pits have been documented as an indigenous practice in places like Mali, Burkina Faso and Niger. In Tanzania, a notable example is the “ngoro” technique of the Matengo Highlands in Mbinga District. In semi-arid Tanzania, pits are typically about 30cm in diameter and 20cm deep. The system is well adapted to hand cultivation and is beneficial especially when soil surface capping is a problem.

- Micro-Catchment RWH

Micro-catchment RWH comprises a group of techniques for collecting overland flow (sheet or rill) and delivering it to a cropped area in order to supplement the inadequate direct rainfall. This system involves a distinct division of catchment area and cropped basin, but the two zones are adjacent. The transfer distance is typically in the range of 5 to 50 metres. Both catchment area and cropped basin are normally situated within the land holding of an individual farmer. The system is therefore sometimes known as an "internal catchment" system.

The short transfer distance ensures that the system offers relatively high runoff efficiency, possibly yielding as much as 50% of precipitation compared with as little as 5% contribution to streamflow in a natural catchment. The small catchment size ensures that the flow volume and speed are limited and soil erosion is therefore relatively easy to control. The main disadvantage of the system is that it involves leaving uncropped areas within the farmer's field. In evaluating the benefit it is therefore important to account for the opportunity cost of the cropped area.

Micro-catchment methods that have been observed in Tanzania include:

1. Strip catchment tillage

This technique (also known as contour strip cropping) involves alternating strips of crops with strips of grass or cover crops. Cultivation is usually restricted to the row planted crop strips. The uncultivated strips release runoff into adjacent crop strips. The system is normally used on gentle slopes (up to 2%) with the strip width being adjusted to suit the slope. The catchment area to cropped basin ratio is normally less than 2:1.

The system is widely practiced in many semi-arid areas, although farmers and extension workers may not recognise it as a RWH measure. Various studies (Hatibu and Mahoo, 2000) have reported reduction in soil erosion and runoff, but little work has been done to evaluate the benefits of this method on crop performance. This system is suitable for most crops and is easy to mechanise.

2. Contour Barriers

This technique involves the creation of cross-slope barriers, which may be vegetative (grass strips) or mechanical (stone lines, earth bunds). The barrier intercepts runoff from upslope and promotes infiltration in the cropped area. In the case of earth bunds, the barrier is designed to be impermeable and water is ponded behind it. Other barriers are semi-permeable and aim to slow down and filter runoff without ponding.

Contour bunds have been advocated widely (Rwehumbiza *et al.*, 1999) in the past as a method of soil erosion control on slopes up to 5%. They are generally constructed manually with soil either being thrown up or down slope. The downslope (*fanya chini*) is the common method used in the steep slope areas of Tanzania. Bunds are usually closely spaced (2 to 5 metres). Poor maintenance of the bunds can often lead to failure of the management approach. The risk of failure is reduced if intermittent structures rather than continuous contour bunds are created. These structures (sometimes described as demi-lunes or lunettes) are found as a traditional practice in parts of West Africa.

Stone barriers offer advantages over earth bunds in certain circumstances. In particular, the risk of overtopping and progressive failure due to flow concentration is reduced. Stone lines are usually constructed manually approximately following the contour at spacing of 15m – 30m depending largely on the amount of stones available. They are recommended for slopes up to about 2%.

Semi-permeable barriers can also be formed using trash lines (straw, crop residue, brushwood) or live barriers (grass strips, contour hedges). Trash lines are known to be in use as a traditional practice in Tanzania (Rwehumbiza *et al*, 1999). Grass strips are similar in principle to strip catchment tillage, but normally involve a narrower band (1m) of a specially planted grass species. Contour hedges, possibly using leguminous perennials, can also provide an effective barrier. These can be combined with stone barriers. However, this approach is better suited to humid environments, since competition for moisture is likely to be a problem in semi-arid conditions.

3. Basin Systems

This practice is commonly known as the “negarim” micro-catchment technique and is perhaps the best known RWH system. It is also known as the *meskat* system. In this system, each micro-catchment feeds runoff to a discrete cropped basin. The basin size is typically in the range $10m^2$ to $100m^2$ and is surrounded by an earth bund approximately 30 to 40cm high. They are particularly suited to tree crops, but other crops can be grown successfully under non-mechanised farming systems. There is a long tradition of using this system in arid regions with low intensity winter rainfall (Evenari *et al*, 1971; Oweis and Taimeh, 1996). Few examples of micro-catchment basin systems have been reported in Tanzania. However, it is apparent that some farmers recognise the natural redistribution of runoff that occurs in the farming landscape and adjust their management to reflect differences in land capability.

- Macro-catchment RWH

Macro-catchment RWH comprises a group of techniques for harvesting runoff from a catchment area (CA) and delivering it to a cropped area (CB), where CA and CB may have markedly different characteristics (e.g. slope and soil) and transfer distance may be in the range 100 metres to several kilometres. The catchment generally lies outside the land holding of the farmer(s) using the runoff, so the system is sometimes known as an “external catchment” system (Gowing *et al.,* 1999). This distinct separation can be particularly beneficial if runoff events can be harvested at times when there is no direct rainfall in the cropped area.

The runoff efficiency is normally less than for a micro-catchment system, but the large catchment area ensures that the runoff volume and flow rates are high. This gives rise to problems in managing the peak flows, which can lead to soil erosion and/or sediment deposition. Substantial channels and runoff control structures may be required and this usually involves collective effort amongst a group of farmers for construction and maintenance (Gowing *et al.,* 1999; Hatibu and Mahoo, 2000). This in turn can lead to problems over management of the distribution of the water resource.

Macro-catchment RWH techniques are seen as being the most relevant in relation to common pool resources (CPR). Examples include:

1. Hillside systems

These systems exploit hillslope runoff processes by which runoff from stony outcrops and grazing lands in upland areas tends to flow naturally downslope. Some farmers grow their crops in wetter lowland areas, which receive runoff in this way without any active manipulation or management. Farms in these areas are called *mashamba ya mbugani* and are found throughout semi-arid Tanzania grown with maize, rice, sugar cane, vegetables and bananas. They are attractive not only for their improved moisture regime, but also because of higher fertility levels due to enrichment.

One technique for improving the capture of hillslope runoff involves the construction of cross-slope barriers and basins using earth bunds to intercept and store runoff. In principle, these systems are similar to contour barriers and basin-type micro-catchment systems, but they involve larger external catchments.

An alternative technique involves the construction of hillside conduits, which are dug along the contour to intercept runoff and convey it to an area suitable for crop production. The construction effort is justified if the hillslope runoff would otherwise not reach land that is suitable for cropping. This tends to be the case where low-intensity rain falls on stony hillsides (Evenari *et al*, 1971; Carter and Miller, 1991).

2. Stream-bed systems

These systems use barriers, such as permeable stone dams or earth banks, to intercept water flowing in an ephemeral stream (wadi) and spread it across adjacent valley terraces to enhance infiltration (Hudson, 1992). This technique is sometimes known as the *liman* system and is difficult to distinguish from spate irrigation. The size of these structures varies a great deal, but some systems run for several kilometres with one structure spilling excess flow to another downslope and so on (Kolakar *et al*, 1983). Normally, planting occurs at the end of the wet season using stored soil moisture.

3. Ephemeral stream diversion

These systems are also difficult to distinguish from spate irrigation, since they involve diverting water from an ephemeral stream and conveying it to a cropped area. One method of distributing the water in a cropped area uses a cascade of open trapezoidal or semi-circular bunds. The water fills the basin and spills around the end of the bund into the next basin (sometimes known as *caag* system) (Gowing *et al.,* 1999). Another method is when the field is divided into closed basins and water distributed either through a channel or in a basin-to-basin cascade using small spillways.

Traditional diversion structures may be earth banks, stone walls or brushwood barriers. They are subject to frequent damage and are likely to be washed away by large floods. Attempts to improve such systems by building "permanent" diversion structures, concrete or stone-filled gabions have often encountered problems with flows passing the structure or with diversion of damaging flows during large floods (Gowing *et al.,* 1999; Senkondo *et al.,* 1999).

4. Storage systems

Macro-catchment RWH systems often yield high volumes of runoff and it may be advantageous to store the water in a reservoir or use it to recharge groundwater. This storage of water can be seen as a common pool resource as farmers will have equal access to the resource depending on the rules instigated by the villages (Rwehumbiza *et al,* 1999). Simple reservoir systems have been widely used for livestock watering. They are sometimes known as "charco dams" or "haffirs". Siltation is often a problem and the labour requirement for sediment removal can be a considerable burden. Evaporation and seepage losses may also be high, but in some cases they are avoided by using sand dams as a method of small-scale groundwater recharge.

2.4 RWH in context

Evidence, that is largely anecdotal, suggests that water harvesting for various purposes is a widespread practice in Tanzania. In most instances the practice is opportunistic, but there are a number of traditional techniques in which runoff collection and distribution is actively managed. Some documented studies exist, but knowledge is patchy. RWH has been largely neglected by research and extension services, but represents the best prospect for sustainable intensification for the vast majority of dryland farmers.

The challenge is to identify and disseminate appropriate technologies that will reduce vulnerability to rainfall variability and scarcity in the semi-arid areas, an objective of this research. Alongside this challenge is that of understanding the application of common property regimes and the instigation of common pool resources – approaches to managing the natural resources fairly so all participants in the agricultural regime benefit.

2.4.1 Application of water collected via RWH techniques

Although the focus of the Tanzanian DSS is on the application of RWH techniques and water capture for enhancing crop production, consideration needs to be given to the other uses of water in Tanzania. The reason being that this will influence how much water the farmers are willing to partition to crop production.

Water application considerations include:

- Water requirements for crops
- Domestic water requirements
- Water requirements for livestock and wildlife.

Each of the above points shall now be discussed and examples related to them expressed.

2.4.1.1 Water requirements for crops

Water used by crops is the leading economical use of rainwater falling throughout Tanzania (Hatibu and Mahoo, 2000). As for all types of vegetation, crop water use is measured in terms of evapotranspiration. The optimum evapotranspiration for a given crop is called crop potential evapotranspiration (ET_{crop}). This is defined as the evapotranspiration by a disease free crop, growing under non-restricting soil conditions including soil, water and fertility and achieving full production potential under the given growing environment (Doorenbos and Kassam, 1979; Dorrenbos and Pruitt, 1977).

Climate, crop type, and stage of growth therefore influence the potential water requirement by a crop. Potentially, more water is required by crops in environments which are sunny, hot and windy with very low relative humidity than in cooler non-windy areas. Since weather conditions vary from day to day, so do the crop water needs (Hatibu and Mahoo, 2000). Potential water needs of crops are therefore calculated based on shorter periods, such as 5, 10 and 30 days rather than on a seasonal or annual basis.

Table 2.2 illustrates the potential evapotranspiration for some crops grown in Tanzania. Maize and rice are the important ones in relation to the development of the DSS.

Crop	**Growth Period (months)**	**ET_{crop} (mm/season)**
Maize	3 – 4	500 – 800
Sorghum/millet	3 – 4	450 – 650
Sunflower	4 – 4.5	600 – 1000
Cotton	7 – 8	1050
Groundnuts	6 – 7	500 – 700
Beans	3 – 4	300 – 500
Rice	5 – 6	900 – 1200
Citrus	Perennial	900 - 1200

Table 2.2: Potential evapotranspiration for selected crops. (Modified from Critchley and Siegert, 1991)

Table 2.3 illustrates rainfall and total crop water requirements for maize and rice for a given period of time. It must be remembered that not all the rainfall actually reaches and stays in the root zone. Therefore, only part of the rainfall is actually available for transpiration. Thus the deficit in relation to optimal crop water requirement is much higher than that indicated by using the full amount of rainfall (Hatibu, 2000).

Also, seasonal rainfall amounts may exceed the seasonal crop water needs with the crop still performing poorly. The seasonal amounts tend to hide times of water surplus or deficit. Prolonged dry spells between rainfall events may lead to crop failure or poor harvest even when total monthly or growing seasonal rainfall far exceeds crop water needs. Thus, rainfall distribution is more important than total rainfall.

Month	Monthly rainfall (R) (mm)	Water requirements (ET_{crop})		Status (R - ET_{crop})	
		Maize	Rice	Maize	Rice
October	3.6				
November	32.6	100.3		-67.7	
December	106.7	156.6	191.4	-49.9	-84.7
January	137.6	135	148.5	2.6	-10.9
February	125.3	112.3	117	13	8.3
March	119.7	72.7	113.6	47	6.1
April	57.1	55.6	111.2	1.5	-54.1
May	5.4		87.6		-82.2
Seasonal	588	632.5	770.3	-44.5	-182.3

Table 2.3: Mean monthly rainfall compared with mean monthly crop water needs. (Adapted from Hatibu and Mahoo, 2000).

Interpretation of the difference between ET_{crop} and rainfall (R) given in Table 2.3 is only related to the situation when the crop is growing at full potential. This is often not the case due to other limitations such as soil fertility. In such situations it is necessary to consider the actual evapotranspiration. This is the actual quantity of water that is removed from the soil by the twin processes of evaporation and transpiration. The quantity is determined by the condition of the crop and available water or both. For example, a crop with poorly developed roots will not transpire water at maximum potential. Actual evapotranspiration is normally estimated as a percentage of the ET_{crop}, depending on the state of health of the crop under consideration.

Depth of the root-zone is a very important determinant of the amount of water and mineral nutrients available to a crop. Ideally, the root-zone should be the same as the potential depth of roots. This is rarely the case for two reasons: either the soil is not deep enough to allow the roots to grow to their full potential, or zones of compaction and relatively impervious horizons act as physical barriers to root penetration.

2.4.1.2 Domestic water needs

People normally give priority to domestic water supply, although pastoralists often give higher priority to water for livestock (Hatibu, 2000). Water meant for other uses would therefore be diverted to domestic and livestock purposes where no other sources are available. The building of charco-dams in many regions of Tanzania have helped increase the levels of water available for livestock, and these systems can also be used as sources of domestic water.

The calculation of domestic water requirements must take into account the daily water requirements per person for cooking and drinking, cleaning and washing. Water required for drinking and cooking has a limited range of 2-5 litres per person per day, this depends mainly on the climate and standards of living. Access to water sources affects the amount of water available for cleaning purposes. For example in semi-arid areas where water is not available near the homes, washing of the body may be accomplished by as little as two litres per person per day.

An example of water consumption by a family of seven during a period of little or no rainfall (the month of June) is illustrated below. This information has been adapted from research carried out by Hatibu and Mahoo (2000).

7 people x 5 litres/person/day x 30 days = 1050 litres (drinking and cooking)
7 people x 2 litres/day x 30 days = 420 litres (body cleaning)
7 people x 2 litres/day x 30 days = 420 litres (utensils washing)
7 people x 10/7 litres/per day x 30 days = 300 litres (clothes washing)

Table 2.4 illustrates the domestic water requirements (in litres) during the dry months of June to November for the semi-arid areas of Tanzania.

Month	Drinking and cooking	Body cleaning	Dish washing	Clothes washing	Total
June	1050	420	420	300	2190
July	1085	434	434	310	2263
August	1085	434	434	310	2263
September	1050	420	420	300	2190
October	1085	434	434	310	2263
November	1050	420	420	310	2190
Total	6405	2562	2562	1830	13359

Table 2.4: Domestic water requirements in litres.

2.4.1.3 Livestock and wildlife

The water requirement of livestock is the total quantity of water used by animals for their metabolic processes as well as for regulating heat in their bodies. They vary according to a number of factors such as food intake, quality of the food and temperature. The voluntary water intake is the quantity of water that has to actually be supplied to animals, and corresponds to the water requirement that cannot be provided by the moisture content of the forage. This is the parameter to be taken into account when planning a water supply system for animals.

For comparison purposes in semi-arid and tropical regions, a common unit normally used is the Tropical Livestock Unit (TLU), which is equivalent to an animal weighing 250kg. The daily water requirements for different animals during the wet and dry seasons at an air temperature of 27^{o}C are shown in Table 2.5.

Season	Type of Animal	TLU	Total water requirements (l/d)	Voluntary water (l/d)
Wet	Cattle	0.7	27	10
	Sheep	0.1	5	2
	Goats	0.1	5	2
Dry	Cattle	0.7	27	27
	Sheep	0.1	5	5
	Goats	0.1	5	5

Table 2.5: Daily water requirements (in litres per day) of different animals during the wet and dry seasons.

Relevant RWH techniques for supplying water for livestock and wildlife require storage facilities. The installation of RWH systems for livestock water supply is very widely spread in Tanzania, but there is little use of deliberate RWH for wild animals (Hatibu and Mahoo, 2000). The majority of livestock and wildlife drinking water is obtained from large shallow depressions in which runoff water collects during the rainy season. However, most of these dry quickly soon after the end of the rain. Nevertheless, these are important sources of water for livestock and wildlife and could be improved through deepening to increase storage volume and also reduce loss by evaporation. This approach could provide RWH to livestock as well as wildlife. The amount of water involved is very high. For example a depression which is 100 m long x 100 m wide x 0.1 m deep can collect about 1000 m^3 of water. Without proper management, the water will collect and evaporate several times during the rainy season.

The United Republic of Tanzania has compiled various reports associated with policies and frameworks for Tanzania in relation to agriculture and management. One of these reports (URT, 1996) expresses how there are strong policies in force for the adoption of RWH management for livestock, particularly for the beef sub-sector.

2.4.1.4 Smallholder farming and Land Tenure

In planning and designing RWH, consideration should be placed on the existing policies and laws that govern various land-use practices such as reserved land, agriculture and infrastructure.

Land tenure is an important consideration in RWH planning, mainly because it plays a critical role in investments that are related to land use and natural resources management practices (Lazaro *et al.,* 2000). Land tenure is a system of land ownership or acquisition governed by the land laws, land policies and customary land ownership systems that are prevailing. In Tanzania, the National Land Policy of 1995, the Land Act of 1999 and various customary land tenure systems (URT, 1999; URT, 1995) specifically govern tenure. The policy points to the need for having a clear land tenure system to help ensure optimal and sustainable use of lands (Lazaro *et al.*, 2000).

A long term and secure tenure system is desirable since RWH involves long term investments. The National Land Policy states that all land in Tanzania is public and vested in the President as trustee on behalf of all citizens (Lazaro *et al.,* 2000). Land categories include:

General Land

This refers to public land that has not been allocated to either reserves or villages. It includes unoccupied or unused village lands. This is a potential land category for RWH investments.

Reserved Land

According to the Land Act of 1999, reserved land is the land reserved, designated or set-aside under different legal provisions. Examples of these provisions include: Forest Ordinance, National Park Ordinance, Ngorongoro Conservation Area Ordinance, Town and Country Planning Ordinance and the Land Acquisition Act of 1967 (Lazaro *et al.,* 2000). The reserved land can be integrated into RWH systems as catchment to produce runoff. Examples include forests, national parks, towns and roads infrastructure. Reserved lands can also be integrated as area of use in RWH systems. However, it is important to note that the reserved lands are governed by different legislations, and therefore require careful integration to RWH systems (Lazaro *et al.,* 2000).

Village Land

This is under the jurisdiction of the village councils. Village land will continue to be vulnerable to change of hands including land transfers through, for example; allocation by village councils, land transfer by the state and villagers giving land rights to others through selling (Lazaro *et al.,* 2000). Village land is the most important category to consider when planning RWH systems. There are several by-laws at district and village level which govern the use of such land. Some examples (Lazaro *et al.,* 2000) related to the prevention of soil erosion and water conservation in Same include:

- No person shall cultivate, cut any tree, grass or graze animals on any prohibited area.
- Any person who cultivates on any preserved or restricted area shall obtain a written permit and comply with the conditions endorsed on the permit issued.
- Any person cultivating on any restricted area which is a slope or valley, shall for the purpose of preventing soil erosion and conservation of water, cultivate and maintain terraces and shall erect hedges if he is required to do so by an agricultural or authorized officer.

It is important that by-laws like these are considered when discussing potential agricultural management options with the farmers in the study region to ensure full compliance with village policies.

The population of rural agriculture smallholder households in Tanzania is 24,743,990, of which 12,304,187 are males and 12,439,803 are females (FAO Statistics). The rural agriculture smallholder population has increased from around 15 million in 1988 to approximately 25 million in 2003. Shinyanga and Mwanza regions have the largest rural agriculture population in Tanzania (2,426,406 and 2,134,382 respectively), Dar es Salaam region and Zanzibar have the smallest (99,030 and 540,508 respectively). The rural agriculture population consists of a high proportion of young people (www.nbs.go.tz/agric_presentations).

The total number of rural agriculture households in Tanzania is 4,901,837 of which 4,804,315 are on the Mainland and 96,522 are in Zanzibar. There are 3,935,761 male headed households and 966,076 female headed households in the country and the average household size is 5.2 persons per household, with Shinyanga having more than other regions (6.4) and Mtwara having the smallest number (4.0 persons per household) (Omari Mzirai, Personal Communication, 2004). Most rural agriculture households are involved in crop production. The number of crop growing households has increased at a rate of 3.2 percent per year over the last ten years (www.farmafrica.org.uk).

Most smallholders have right to land through customary law (68% of total allocated land) and only a small percent is under official land titles (5%). The highest percent of land under customary law are found in Ruvuma (83%) and Mara (78% and the lowest are found in Zanzibar (32%) and Dar es Salaam region (33%). There has been little change in land ownership patterns over the last 10 years (www.nbs.go.tz/agric_presentations).

Most households have got easy access to their fields with only 10 percent of rural agriculture households having the nearest fields at a distance of over 3 km from their homesteads. Smallholders in Kagera, Dar es Salaam and Kilimanjaro have the easiest access to their fields, whilst Mtwara has the worst access.

Crop farming is the most important livelihood activity followed by forest resources and livestock keeping and this is the same for most regions. Off farm income is one of the least important activities and permanent crop farming is not important in terms of livelihood in most regions. About 68 percent of the rural agriculture population works full time on farm and only 3 percent never works on the farm. However there are large regional differences, with Dodoma and Arusha having the highest proportions of fulltime farmers (about 90%) and Manyara having the lowest (with less than 25%). Most rural agriculture households have at least one member involved in off-farm activities (72%).

The sale of food crops is the most important cash earning activity for rural agriculture smallholders. Cash crops and other casual earnings are also important. Sale of livestock, fish and forest products are least important for cash income (Mwakalobo *et al*,. 1999).

The distance to the main source of drinking water is less than 1 km for most households and there is little difference between seasons, with the exception of drinking water sources located 3 km or more (Geophrey Kajiru, Personal Communication, 2004). Fifty percent of households obtain drinking water from a distance of 3 km or above in the dry season. Around 25 percent of households obtain water from unprotected wells, however there is a high percent of households obtaining water from piped sources (24%). The highest percent of protected water sources are found in Arusha, Kilimanjaro, Zanzibar and Dodoma, whilst the least are in Tabora, Mara and Pwani.

Heads of households are mostly involved in fishing, cattle marketing, fish farming, bee keeping and goat and sheep marketing. Adult females are mostly involved in beer making, collecting firewood, crop processing, collecting water and milking. Children are mostly involved in livestock herding. In most households soil preparation by hand, planting, weeding, harvesting and crop protection are done by adult male and females, however in many households these activities are carried out by all household members (www.ifpri.org).

Most rural agriculture households assign 1 to 25 percent of their livelihood activities for non - subsistence purposes and very few households use more than 75 percent of their livelihood activities for non subsistence purposes.

Most rural agriculture households in Tanzania take 2 meals per day. Very few households take more than 3 meals a day or one meal per day. However, large differences exist between regions with Tanga region having the highest proportion of households that take three meals per day and Rukwa and Kagera the lowest (www.nbs.go.tz/agric_presentations).

Most households in Tanzania consume animal protein at least once in a week, and 49 percent of the households eat animal protein at least 3 times a week. However 19 percent of households do not eat animal protein in a week and most of these are found in Shinyanga, Dodoma, Kigoma and Arusha.

2.5 RWH Conclusion

In the semi-arid areas of Tanzania, agriculture and the livelihoods that depend on it are greatly affected by the unreliable and highly variable rainfall regime.

Any attempt to improve agriculture therefore must tackle the moisture constraint, but knowledge of appropriate techniques is surprisingly poor. It appears that a significant knowledge gap exists between two areas that have previously received far greater attention. On one hand, widespread concern about land degradation has led to a focus on soil erosion control. On the other hand, efforts to exploit water resources have led to a focus on irrigation. Between these two extremes, the middle ground of RWH has been largely neglected. The challenge is to identify and disseminate appropriate technologies that will help to reduce farmer's vulnerability to drought.

Various critical reviews (e.g. Senkondo *et al.,* 1999; Gowing *et al.*,1999; Kajiru *et al.,* 1999) point out the reasons why approaches to impose technical solutions on unwilling farmers tend to fail. In additions to these critiques, Hudson (1991) identifies reasons for success and failure, and defines what new farming practices should offer in order to be adopted by farmers.

More recent studies (Hatibu and Mahoo, 2000; Hatibu, 2002; Matthews and Stephens, 2002) have identified the emergence of a new style of natural resource management, that is based on participatory approaches (questioning farmers with regard to their agricultural conditions), which has provoked a re-evaluation of indigenous soil and water conservation techniques. The question then became: 'How can external interventions transfer knowledge and facilitate technological innovation by farmers?' (Rwehumbiza *et al,* 1999).

It is important that RWH is regarded as a continuum of techniques that link in-situ soil water conservation at one extreme, to conventional irrigation at the other. RWH can be described as the practice of collecting rainfall runoff for cultivation. Various attempts have been made to classify the different techniques according to the nature of the runoff process involved (Senkondo *et al,* 1999; Lazaro *et al,* 1999). In general classification is according to the size ratio and transfer distance between runoff producing, normally called the catchment area, and the runoff receiving area (the crop basin).

The information above demonstrates the different catchment areas of the land that is receiving runoff and rainfall. It is therefore now necessary to discuss the catchment areas that have made up this research, as well as giving a brief description of Tanzania as a semi-arid country.

2.6 Profile of Tanzania and the study regions

Tanzania lies on the east coast of Africa with a land area of approximately 1 million km^2. It is bordered by Kenya in the north and shares Lake Victoria with Kenya and Uganda in the west. It has frontiers with Rwanda, Burundi and Zaire in the southwest, and with Zambia, Malawi and Mozambique in the south (www.tanzania-web.com). The population in 1995 was 28.5 million, growing at 3% per year (FAO Statistics, 2001). Nearly 77% of the people live in rural areas and depend upon agriculture for their livelihoods. Figure 2.9 below shows a map of Tanzania illustrating the countries that surround it.

Figure 2.9: **Map of Tanzania** (www.tanzania-web.com). (1cm = 450km approx)

The climate of Tanzania is tropical. Rainfall is generally low and unreliable, with only a few areas receiving more than 1000 mm annually. Rainfall in most of the north is bimodal. Rains usually start in October and end in May, with dry months in January and February. The bimodal rains mean that drought affects many agricultural species that are and can be grown. The south experiences a single wet season from November to April. The normal temperature pattern is affected by altitude over most of the western half of the country, with mean minimum temperatures below 15^{o}C from June to August. Light intensity is good throughout the country which benefits the growth of many agricultural species. (http://www.tanzania.gov.tz)

As mentioned, agriculture is of particular significance to Tanzania. Rice is one of the main crops, with 60% of the population eating some rice. Because the increased production of rice has not met consumption demands, imports continue to be necessary (FAO Statistics, 2001). For example in 1994, Tanzania imported 90,000 tonnes of milled rice. Only about 16% of the 40 million hectares suitable for arable cropping are used for farming. About 17 million hectares are thought to be potentially suitable for rainfed or irrigated rice.

In the 1980's crop yields were seen as excellent (FAO Statistics, 2002). Since then, the problems with management, shortages of investment capital for equipment, increasing weed problems, and loss of level fields (through increases in infrastructure) have become increasingly serious. The constraints experienced by family farmers – those who tend to grow food for their own consumption and livelihood maintenance – are somewhat different from those affecting the state farm sector – those who produce food products for selling and export. Investments are essentially zero and most farmers' use traditional varieties or landraces of crops. Most family farms do not have irrigation water on demand.

Developing irrigation systems and improved management of resources would help to increase crop production. With irrigation water on demand, farmers would be more likely to risk the investment in improved varieties and other inputs necessary to increase yields. It should however be noted that although irrigation techniques would be of great benefit in principle, in practice it is often unfeasible as there are not sufficient resources available to instigate a substantial irrigation system.

One alternative to irrigation is to capture, store and use rainwater to supplement annual rainfall and buffer the system against periodic drought. This is the concept of RWH (Barrow, 1999).

For this research, two catchment areas in Tanzania were selected – Maswa and the Western Pare Lowlands (WPLL). Both catchments are similar in that they receive variable rainfall both between and within seasons. However, they differ with regard to topographical details. WPLL is much more rocky and the land relief is steeper. The predominant soil type is that of *Ngamba* (Kajiru, Personal Communication, 2002); a fertile soil good for growing maize. The soils in Maswa are more varied allowing for a greater number of crops to be grown. Previous agricultural studies have been carried out in these regions by Sokoine University, hence advanced knowledge and understanding of these regions already exists. This existing knowledge was a contributing factor in terms of why Maswa and WPLL were chosen for this study. Within each catchment three villages were designated as study areas. Plates 2.1 to 2.3 illustrate the general picture in the study regions – (1) cropping systems (maize), (2) rice fields, (3) farming practices.

Plates 2.1-2.3**:** Photographs to illustrate the general picture in the study regions

Further details pertaining to the land characteristics and locations of the study catchments shall now be presented.

2.6.1 The Study Areas

The study was conducted in two areas,

- Western side of the Pare Mountains in Same and Mwanga Districts. This study area is referred to as the Western Pare Low Lands (WPLL)
- Maswa District

Figure 2.10 below illustrates the location of the two study regions. This is a simplified and stylised map, provided by the team of researchers in Tanzania.

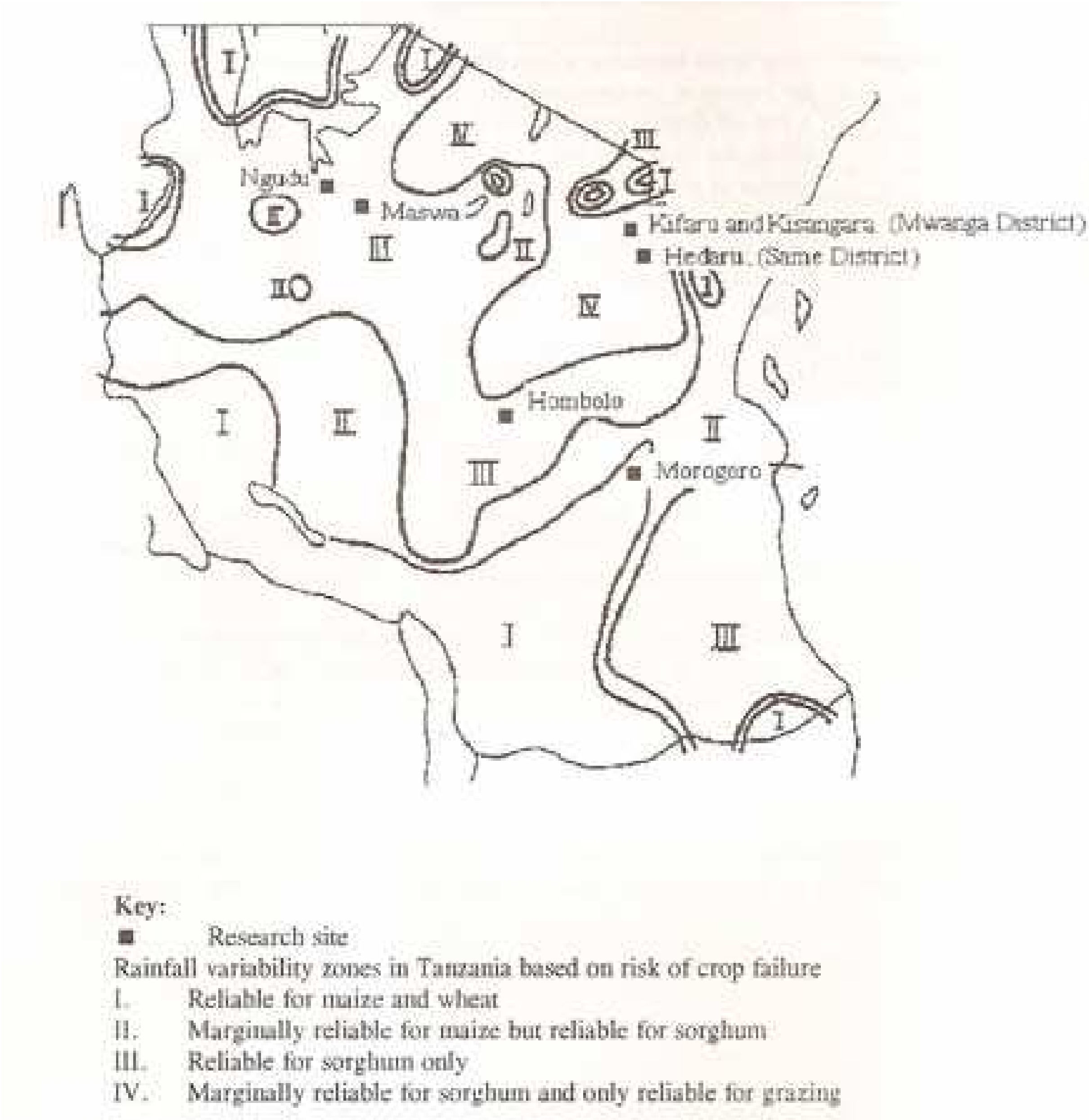


Figure 2.10: Map illustrating the location of the two study regions for this research – Maswa and WPLL (Same and Mwanga districts). (2cm = 450Km approx).

The WPLL are located on the western part of the former Pare District (now Mwanga and Same Districts) and stretch eastward from Kifaru and Hedaru villages. The study area is located at latitudes 37^{o} 36’ to 38^{o} 00; S and longitudes 3^{o} 36’ and 4^{o} 36’ E. It lies at an altitude ranging from 500 to 1200 m.a.s.l (metres above sea level).

Maswa District in Shinyanga region is located approximately at latitudes 2^o 50’ to 3^o 38’ S and longitudes 33^o 30’ to 34^o 15’ E. The district lies at an altitude of 1200 to 1300 m.a.s.l.

Figure 2.11 – 2.15 illustrate the study areas on a clearer map of Tanzania.

Figure 2.11: Map of Tanzania showing the two study regions. (1) Maswa, (2) WPLL. (Source: BP Transport Map) (1:1,250,000. One full square on the map = 60 miles in length)

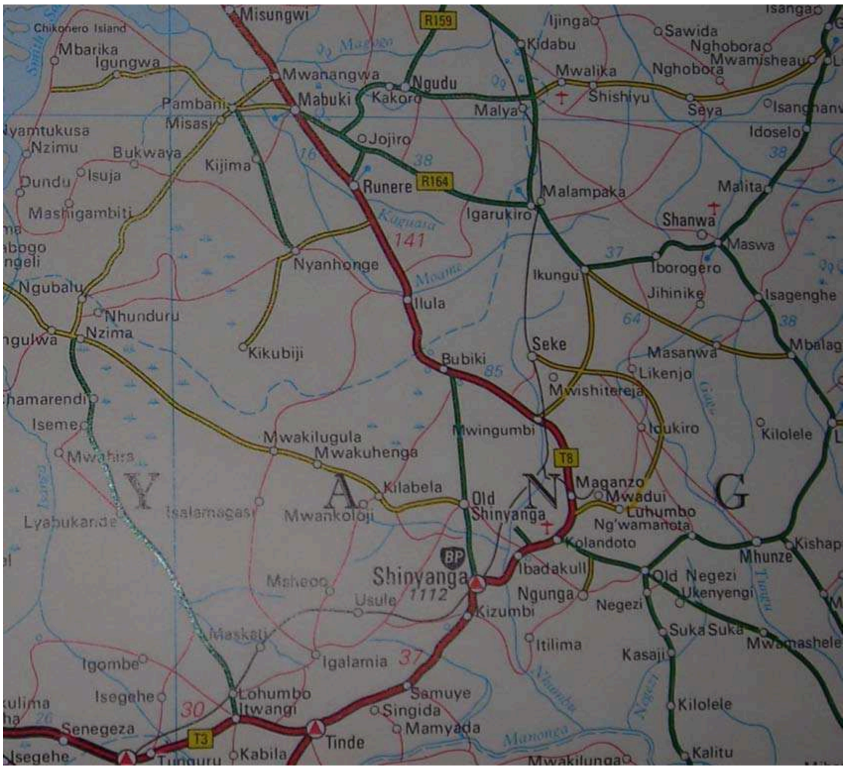


Figure 2.14: Maswa – further enhancement (adapted from the BP Transport Map). (1:1,250,000. One full square on the map = 60 miles in length)

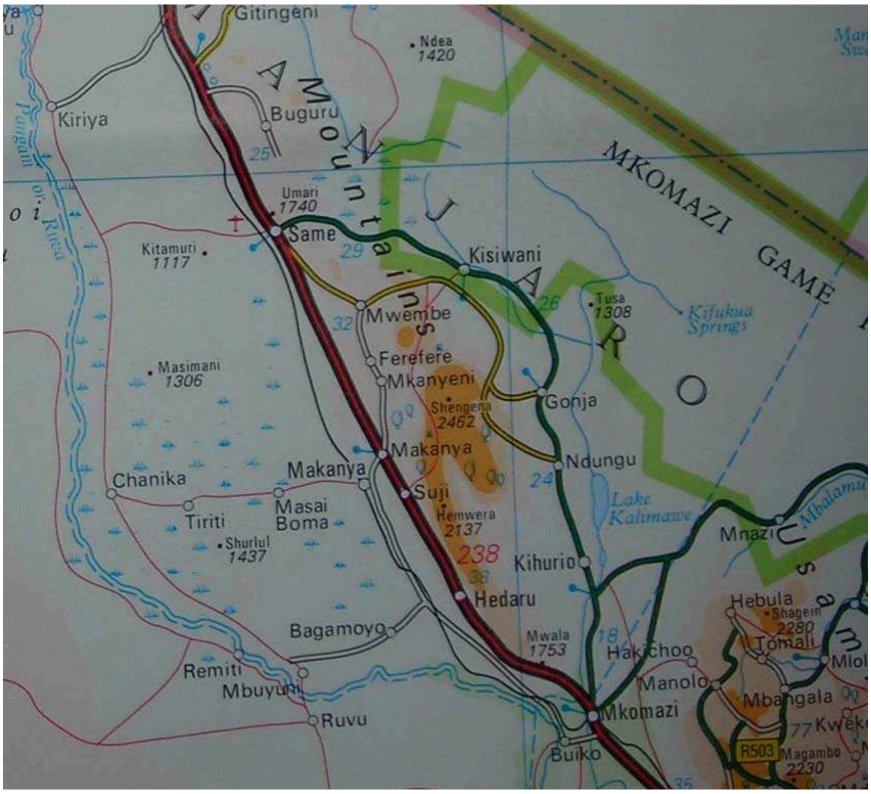


Figure 2.15: WPLL - further enhancement (adapted from the BP Transport Map). (1:1,250,000. One full square on the map = 60 miles in length)

Maswa and WPLL were chosen as the study areas as extensive previous studies had already been performed on the areas by the team in Tanzania. The collection of physical data and observations were carried out by the scientists and extension officers working in Tanzania. The information collected in these study areas for use within the development of the Tanzanian DSS was obtained using three different methods.

1. An assessment of agro-ecological zoning as done by De Pauw (1974). This was used to provide an overview of the general toposequence in the study areas.
2. Reconnaissance soil surveys and limited semi-detailed soil surveys of the sites where experimental fields were located. These surveys were done according to approaches described by Dent and Young (1981) and covered both study areas.
3. Rapid and participatory rural appraisal techniques were carried out in the study areas as described by Chambers *et al* (1989). The appraisals involved the collection of multiple types of information. The important aspects that were collected for the production of the Tanzanian DSS were related to landscape characteristics and their effects on the management of RWH. The information was mainly obtained using transect walks and wealth ranking. However, discussions and workshops were also held with villagers to ascertain information.

These techniques for gathering information about the study areas were applied in the hope of being able to understand the likelihood of success of RWH regimes in the study areas. Some of the information obtained shall now be highlighted. Particular focus is on RWH and the understanding of land characteristics in the study areas.

Rwehumbiza *et al* (1999) state that the characteristics of the catena determine the potential for RWH. The following diagrams (Figure 2.16) illustrate in schematic form the different types of landform and its effect on runoff generation and rainwater harvesting.

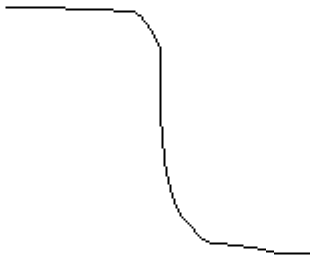
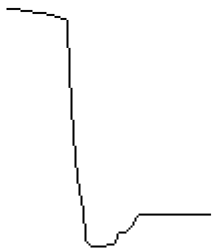
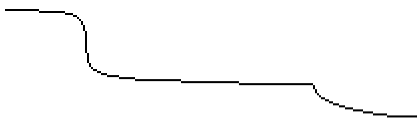
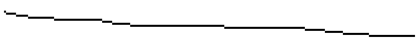
Land Form	Attributes and RWH potential
	Very steep catchment, runoff in deep gullies and moves fast. Difficult to use in the pediment but spreads naturally further down in the lowland plains where it is opportunistically used by farmers. A good example is Kifaru village in Mwanga **High potential for RWH**
	Very steep, a lot of runoff, no area at the bottom to use it. Common in Morogoro. **Poor potential for RWH**
	Runoff generating area well matched with receiving area. Common in some parts of Maswa District. **High potential for RWH**
	Small area generating limited runoff, large area on which to use it. Demand of water exceeds supply. Common in many areas of Maswa District. **Medium potential for RWH**
	Too flat to generate runoff **Low potential for RWH**

Figure 2.16: Schematic presentation of landform and its effect on runoff generation and rainwater harvesting. (adapted from Rwehumbiza *et al*, 1999)

Information shall now be presented to give a greater understanding of the study areas and their land characteristics.

Western Pare Low Lands

According to De Pauw (1984) the WPLL is classified under one major physiographic region, known as the Eastern Plateau and Mountain Block. This is further divided into two smaller physiographic sub-units namely: medium altitude, gently undulating to rolling plains and flat and wide depressions. The medium altitude plain is dominated mainly by undulating topography while the flood plain is characterised by flat and wide topographical depressions developed on young alluvium.

The terrain on the upper part is strongly dissected and composed of steep rocky hills and sloping pediments (10 – 40%) developed on intermediate metamorphic rocks (De Pauw, 1984). On the foot of the mountains, there are flat and wide topographical depressions developed on young alluvium. The flat alluvial plains towards river Pangani are poorly drained and contain some pockets of salt affected soils. The landscape of the WPLL study area portrays the characterists of a catchment with very steep slopes and only a limited area for using the runoff (Rwehumbiza *et al*, 1999).

This information can be outlined in Figure 2.17 below.

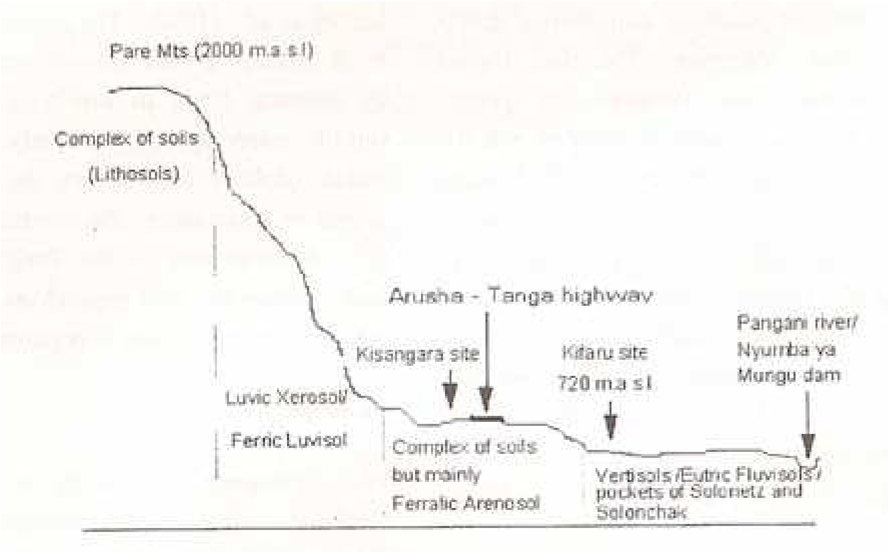


Figure 2.17: WPLL – a catena based on soil survey by Rwehumbiza and Diwani (1998)

The management of generated runoff is complicated by local infrastructure such as roads, railway culverts and bridges. The effect of too much runoff generated by steep slopes in these areas was observed by Anderson (1982) and Kisanga (1997) who discuss the problems of land degradation on the slopes within the Kilimanjaro area of Tanzania.

Woody bushes mostly cover the steep slopes. However, the slopes are overgrazed during long rainy seasons when the lowlands are cropped and therefore unavailable for grazing. The Maasai from neighbouring Arusha region have brought in large numbers of livestock and therefore grazing land is scarce (Rwehumbiza *et al*, 1999). Felling of trees for fuel wood, charcoal making, timber and poles for house construction and the incessant forest fires and land clearing for crop production have also contributed to the loss of ground cover. As a consequence, high volumes of runoff, which are unmanageable at times, are generated. The runoff is very rapid on the steep slopes and cannot be diverted into crop fields located in the catchment because it flows in deep gullies. Attempts to divert water from gullies has been disastrous. This has been due to the inability by farmers to control the amount of water to be diverted and to spread it safely in the cropped area. Several farmers have had to abandon their fields because diverted runoff had created deep gullies across them (Rwehubiza *et al*, 1999). Big flows into the lowlands were observed by Bakari *et al* (1998). The current trend is for farmers to use runoff opportunistically by planting crops in low-lying areas where runoff water spreads naturally. Maize and lablab (*dolicos lablab*) are the major crops grown in these areas. The lowlands extend for several kilometres to the Pangani river and their greater use will depend on how the runoff from the mountains is managed.

Maswa

The study area in Maswa is located on the Central Plateau (De Pauw, 1984). It is characterised by undulating topography and small hills covered by extensive surfaces of rock outcrops which are interspersed by broad valleys (Mahoo *et al*, 1998). In some cases, the hilltops are covered with thick pockets of trees and shrubs. There is a good understanding by farmers of the soils and the type of crops to be grown (Kajiru and Mzirai, Personal Communication, 2003).

The largest part of the landscape is flat to gently undulating plains (0 – 3% slope) developed partly on granite, partly on old colluvium and alluvium (De Pauw, 1984). *Vertisols, Sodic, planasols* and *Gleyic Solonetz* constitute about 50 -60% of the soils (Rwehumbiza, 1999). The exact extent of each of these soils varies from one area to another. Occurrence of crusts of salts during dry periods is a common phenomenon and there is considerable seasonal waterlogging.

Unlike the WPLL, which have very steep mountains overlooking the lowlands, this area has small hills that cover relatively small areas compared to the extensive plains.

Figure 2.18 below illustrates the catena for the Maswa district. It is possible to compare this with figure 2.17 for the WPLL, differences can be observed.

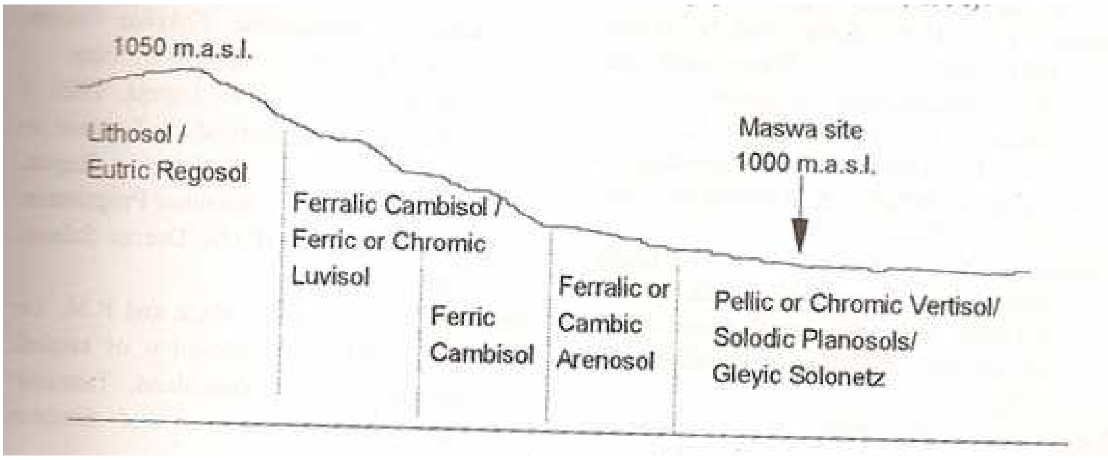


Figure 2.18: A catena across the Maswa district. Constructed with information from Meertens *et al*, (1999), Mahoo *et al*, (1998), Ngailo *et al*, (1984) and De Pauw (1984).

Rainwater harvesting is widespread, and most runoff is harvested into bunded paddy fields (called *majaluba)* (Rwehumbiza *el al*, 1999). The generated runoff is substantial but it is not adequate enough to meet the water demand of the expanding rice production. Good knowledge prevails among farmers on local techniques of RWH and management in the paddy fields (Rwehumbiza *et al*, 1999; Kajiru, personal communication, 2002). Many of these techniques have been outlined in the section above that gives details about RWH. Runoff is harvested from a wide range of sources in Maswa, including:

- Foot and cattle paths
- Roads and road culverts
- Rock outcrops on the hills

The other major source of water is from seasonal rivers which flow only during the rainy season. In the dry season the major source of water is either from charco-dams, shallow hand dug wells and subsurface water from dry riverbeds.

Despite the limited availability of runoff, it is in Maswa where there is a high degree of rainwater harvesting. However, shortage of runoff water is one of the major constraints for rice production (Meertens *et al*, 1999). This is a consequence of the relatively large area on which runoff is used, compared to the smaller runoff generating area (Rwehumbiza *et al*, 1999). However, despite this constraint, rice production using RWH contributes nearly 50% of the total rice production in Tanzania (Meertens and Lupeja, 1996; MoAC, 1998).

Studies have been carried out by the team in Tanzania to establish a greater understanding of the extent to which RWH is in place within the study areas. Particular focus has been on the WPLL as RWH techniques are soundly employed within Maswa already (as stated above). One of these studies, looking at the adoption of RWH technologies by farmers in Tanzania shall now be highlighted.

2.6.2 Study areas – photographic representation

Illustrated below are some photographs that were taken when Dr Sayed Azam-Ali from the Nottingham research team visited the two study regions in Tanzania. They help to give a pictorial representation of the prevailing agricultural conditions.

Plate 2.4: Farmers in a trial plot field in Maswa. The initial stages of maize growth can be observed. Channels can be seen to the left of the photograph that can be used for diverting water into the cropped area. The soil looks moist and crops have established themselves well. Limited management is applied in these early stages of crop establishment.

Plate 2.5: Example of agricultural practices in Tanzania, an ox-drawn plough. These are used in both Maswa and the WPLL generally by the richer farmers who can afford to use machinery on their land.

Plate 2.6: Distinguishing between trial plots in Maswa. The channels highlight the gullies used for capturing water. The soil looks quite wet and clayey. The crops have not established themselves in these plots yet.

Plate 2.7: Geophrey Kajiru from the SUA team performing some of the experimental work in the field and checking the field plots.

Plate 2.8: A more established representation of the Maize crop, nearing harvest time.

Plate 2.9: Water reservoir for growing rice located in WPLL.

Plate 2.10: Tanzanian landscape - Maswa

Plate 2.11: Maize crop at the stage of harvesting

Plate 2.12: A water channel that needs to be tapped for utilisation of the resource

Plate 2.13: Further example of the capture of water and the relief of the land in Tanzania

More example photographs from the study regions can be found in Appendix 1.

2.7 Adoption of RWH technologies by farmers in Tanzania

Adoption of technology is an important factor in economic development. Successful introduction of technologies in the developing countries requires an understanding of the priorities and concerns of smallholder farmers at the grassroots. Many adoption studies have been undertaken to single out the most important factors that determine the diffusion of innovation (Senkondo *et al*, 1999).

Feder (1985) defines adoption as the degree to which a new technology is used in long run equilibrium when farmers have complete information about the technology and its potential. On the other hand, aggregate adoption is defined as the process of diffusion of a new technology within a given geographical region. Adoption at the farm level is related to the decisions made by farmers to use that particular technology in the production process. Nkonya (1997) pointed out that factors affecting adoption differ across countries and are location specific, thus calling for studies that are location specific.

Very few studies have been carried out in Tanzania with respect to the adoption of RWH. Findings from adoption studies are an important tool to extension workers, researchers and policy makers involved in RWH programmes. Knowing the characteristics that have determined the adoption and diffusion of technologies would indicate what characteristics new technologies should posses to become quickly and widely adopted.

There is a need to understand the relative importance of factors and constraints which may influence individuals' adoption of RWH technologies and thus stimulate people's willingness to invest in RWH technologies. With regard to Tanzania, the need for RWH technologies is to help increase domestic food production and achieve food security. However, much of the agricultural land in Tanzania is located in arid and semi-arid land areas (about 50% of the total land area in Tanzania) where rain falls irregularly and much water is soon lost to surface runoff. RWH is one method that can be used to manage the scarce rainfall in semi-arid areas in order to enhance agricultural production. Adoption of various RWH technologies in arid and semi-arid areas is therefore likely to bring about sustained agricultural production, which will improve food security of the rural people (Senkondo *et al*, 1999).

RWH can be defined in various ways (as already stipulated), however, a basic definition is that given by Myers (1975) as "any system that encompasses methods for collecting, concentrating and sorting various forms of runoff for various purposes". RWH technologies used in Tanzania vary from in-situ methods (e.g. deep tillage, contour farming and ridging) for conserving rainwater where it falls, to a system for diverting ephemeral streams and culvert discharges to provide supplementary water for crop production. RWH technology therefore encompasses soil and water conservation and partly supplementary irrigation. It is therefore a complicated technology with multiple requirements for it to be adopted. In addition, it is not easy to draw a clear line between adopters and non-adopters of RWH (Senkondo *et al*, 1999). Thus, the use of intensity of adoption i.e. the proportion of the area applied with RWH or carefully defining adopters and non-adopters, assist in solving this.

One of the most important factors when determining whether a new technology is likely to be adopted is to have a clear understanding of the farmers' perceptions towards the new technology. Alongside this, a clear understanding of the users and non-users is also required. An important step for the identification of users and non-users of RWH technologies is to have an understanding of farmers' perceptions of the technologies. Discussions with key informants have been held to determine their understanding of RWH. The basic results from these discussions showed that farmers agreed that RWH involves the collecting of rainwater in the fields and conserving it. For effective RWH, they noted that there should be one of the following:

1. existence of a river, gully or rills
2. canals for diverting water into fields
3. water reservoir
4. canals to divert water from the reservoir to the field

The types of RWH techniques that were identified by the farmers were as follows, as adapted from Senkondo *et al* (1999):

Deep Tillage

Farmers noted that deep tillage collects and conserves moisture in their fields. This practice is either done manually or by tractor. Farmers noted that there is a big difference between a field which has been tilled and that which has not. The yield difference is as high as 50%.

Diversion of rainwater from gullies

Farmers defined gullies (*makorongo*) as water streams that flow during the rainy season only. They usually dry up during the dry season. Construction of diversion channels is either done individually or communally. Farmers with adjacent fields sometimes construct channels to divert water to their fields.

Collection of water from rills/sheet flow

Farmers defined rills as tiny or small gullies. They therefore construct channels to collect water from rills and/or sheet flow and direct this into their fields. This is usually done individually. This practice is common in areas without permanent water sources.

Diversion of water from rivers

Farmers differentiated rivers from gullies in that water flows in the rivers throughout the year. They do not dry up during the dry season. However in some instances there was some confusion as some rivers that used to flow all year round now dry up in the dry season due to over exploitation. Diversion of water from rivers involves the construction of canals from the rivers to divert the water to the fields. This practice is common in upland areas where the rivers flow throughout the year.

As well as using water for enhancing crop production, the farmers questioned in Tanzania raised considerations and concerns for the use of water for livestock. Three practices that are commonly used were identified.

Ndoroto

Ndoroto is described as a natural land depression, which collects water during the rainy season. Livestock are then brought into these sites for watering. These depressions usually dry up during the dry season.

Lang'ata

Lang'ata is a site along a riverbank which is shallow. They are common sites where livestock can cross a river during grazing or travelling from one place to another. Livestock are therefore brought to these sites for watering. During the dry season, farmers can travel great distances to find the nearest *Lang'ata* for watering the livestock.

Makono

These are described as natural canals, which develop during flooding of rivers. The water remains in the canals for along time after the river subsides. Even during the dry season the soil remains moist and is often used for crop production. Some farmers own these canals privately (individually). This often creates conflict between livestock watering and crop production.

Also during the discussions held with farmers, aspects related to understanding soil fertility and soil types were determined. As illustrated in Tables 2.6 and 2.7 the scientific terms for the different types of soil have been outlined. These terms however are relatively insignificant to the actual farmers in the field. It can be stated that the farmers have their own terms that they use for the soil types and have their own understanding towards the different fertility of these soil types. This information is displayed in the following tables.

Soil Definitions

	Mbuga	Ibushi	Itogolo	Ikerege / Ibambasi	Shigulu	Shiglugu	Ilago / Shinele	Luseni	Ngamba	Mthau mkundu	Mshangagaa
Soil Characteristics	Cracks, heavy, sticky, clay, easily cultivated when dry.	Heavy, grey, sticky when wet	Black, mixture of other soils, found on sloping land, sticky when wet	3 types: red, white and black. Sandy texture. Difficult to cultivate	Site of an old anthill, black, clayey	Site of a kraal. Sandy, more humus, friable	Wet, sandy, black, sticky. Stones present. 'Cold' soil	Sandy, porous, reddish or white, no clay, 2 types.	Cracks in dry season, heavy, sticky when wet, clay, easily cultivated.	Red-brown colour, presence of iron	Sandy, porous, reddish or white, no clay
Depth	Deep, height of a person, below soil there is sand and water	2m	Shallow soil, hardpan at 10cm	Very shallow	Very deep	30cm to 2m	30cm sandy soil underneath	Deep. 3m to find hardpan	Very deep	Moderately deep, 1m	3m
Soil fertility	Very fertile	Fertile	Fertile.	Poor	Fertile	Very fertile	Low fertility	Poor	Fertile – most fertile of the soils	Low in fertility	Poor
Crop grown	Maize, green gram, cotton, chick pea, rice, vegetables	Maize, cassava, sweet potato, groundnut, cotton, sorghum, cowpea, green gram, cucumber	Varies. Cotton, sorghum, groundnut, green gram if rain is poor. Rice if rain is good.	Sorghum, cotton, groundnut, green gram, rice. Nothing on the others.	maize, cotton, sorghum, sweet potato, groundnut, cowpea	Maize, cotton, sorghum, green gram.	Sweet potato	Cotton, chickpea. Drier areas grow bambara groundnut, cassava. Wet - sweet potato.	Maize, sometimes intercropped with beans	Maize intercropped with beans	Maize and sweet potato.

Table 2.6**: <u>Soil definitions for Maswa using local terms defined by the team in Tanzania</u>** (Information supplied by Kajiru, 2004)

Table 2.7: **<u>Consequences of cultivating the different soil types</u>**

	Mbuga	Ibushi	Itogolo	Ikerege / Ibambasi	Shigulu	Shiglugu	Ilago / Shinele	Luseni	Ngamba	Mthau mkundu	Mshangagaa
Land preparation and management	Becomes friable, Ploughed with hoes. Plant flat not on ridges. Rice is bunded	Ridges and flat cultivation used	Depending on crop fields are bunded or flat	Avoided for cultivation. Application of FYM. Rainfall needed for cultivation	Worked before or after rains, easy to cultivate, ridge and flat cultivation.	Ridges and flat cultivation used	FYM added to make it more productive. Tied ridges used for rice cultivation.	Easy to cultivate. Ridges used. Cultivation is across a slope. FYM added to improve fertility	Can become friable. Land prepared before rains – March. Plant flat.	Land prepared in March. Ploughed in the dry season. Plant flat.	Easy to cultivate. Cultivate across the slope so water does not run down the slope
Water infiltration	Good infiltration and retention of moisture.	Good infiltration except when saturated	Water does not go deep.	Wet on top only, no infiltration.	Infiltration good, no surface runoff.	Infiltration and retention depends upon topography	Surface runoff on sloping land. Good water holding capacity.	Poor water holding capacity.	Good infiltration and retention of water	Good infiltration	Poor water holding capacity.
Soil Erosion	Surface runoff	-	Runoff does not carry soil	Surface runoff	No gullies found	-	-	Soil can be eroded in heavy rains.	Maybe some soil erosion.	Some erosion	Soil gets eroded in heavy rains
Main problems	Flooding.	American boll worm, striga	Need good rainfall for crops.	Need heavy rainfall, low fertility, difficult to cultivate	Striga, insects, wilting of crops in low rains	Drought causes maize to wilt and die.	Suitable for few crops, waterlogging, leaching of FYM	Poor yields, stunted crops, poor fertility.	Flooding destroys crops, weeds	Poor soil fertility	Poor yields, stunted crops due to poor fertility.

(Information supplied by Kajiru, 2004)

Three important soil types in the two study regions, as identified in the catena diagrams (Figures 2.17 and 2.18) and commented upon in Table 2.7 are described below.

Luseni

Luseni is an example of an arenosol. These are grey to reddish-brown, coarse sandy soils derived from granite parent material. These soils occupy the upper and mid-slopes in the catena. Soil depth is variable and sand content in the topsoil generally exceeds 80%. Due to their coarse texture, permeability is high while water-holding capacity is 30 mm of water per metre of soil. These types of soil are not good for runoff generation (Hatibu *et al.,* 2000).

Itogolo

Itogolo is an example of a planosol. These are hard pan soils occupying lower slopes. They are also derived from granite parent material but have a fine texture. Their important feature is a hard pan layer at about 30-50 cm depth which restricts percolation of water. This encourages rapid saturation of the topsoil leading to high rates of runoff. The soils have available water holding capacity ranging from 30-100 mm of water per metre depth of soil (Hatibu *et al.,* 2000).

Mbuga

Mbuga is an example of a vertisol. These are heavy, light grey to black cracking soils occupying the valley floors. The majority of the fine fractions transported down slope are eventually deposited on the valley floor and in the depressions where they come to form dark coloured, clayey soils (Hatibu *et al.,* 2000).

The importance of this sort of soil information is that it will help in the communication between extension officers and farmers in the field when discussions are held surrounding the best agricultural management options. These local terms can be applied to both study areas – Maswa and WPLL.

Alongside having an understanding of the perceptions expressed by potential users of the RWH technology, it is also important to have information available about the proposed new technologies.

2.7.1 Sources of information in RWH

Adoption of any technology depends to a large extent on the availability of information about the technology (Senkondo, 1999). By making this information available helps to increase the awareness towards a particular technology. The sources of knowledge related to RWH are illustrated in the following table. These sources were identified by the participant farmers in Tanzania – Table 2.8.

Source (Senkondo *et al*, 1998)
- Indigenous knowledge/own initiative - SUA RWH Project - Fellow farmers/neighbours - Non-governmental organisations - Extension workers - Visit to other areas

Table 2.8: Sources of knowledge on RWH

From the research carried out by the team in Tanzania, they were able to conclude that most of the farmers are applying RWH through their own initiatives or through indigenous knowledge. Approximately 60% of the respondents that were surveyed indicated that they applied RWH using their own indigenous knowledge (Senkondo, 1999).

Also the work of SUA (Sokoine University of Agriculture) helped to contribute to a lot of the understanding towards the different methods of RWH through their collaboration with the extension officers and farmers in the field. With regards to RWH it is important to have an understanding of how water moves through the general catena. This can be illustrated by figure 2.19 below.

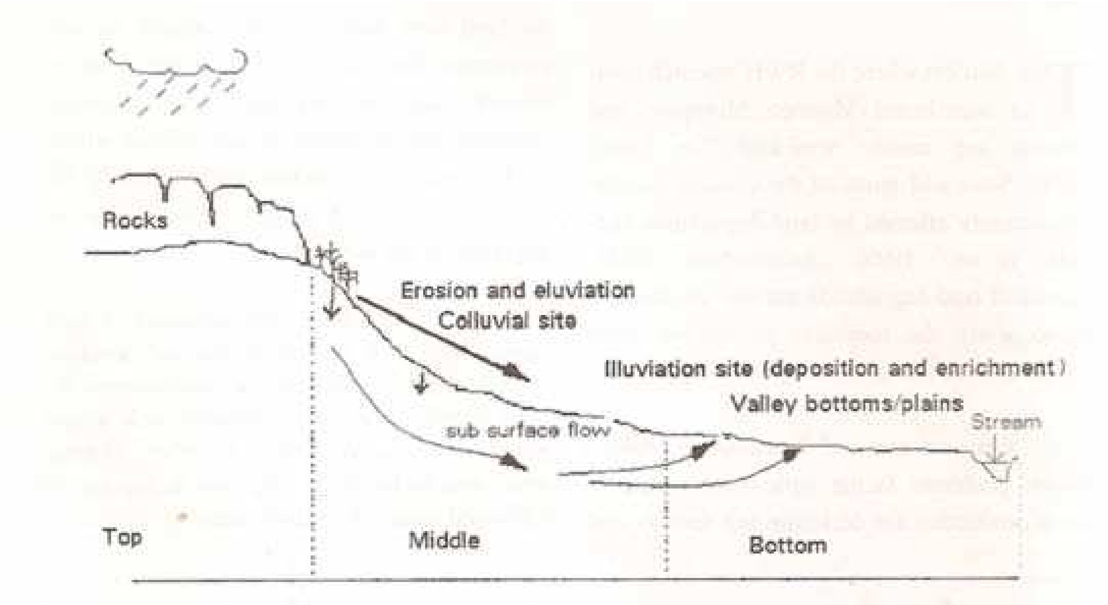


Figure 2.19: Water movement in a generalised catena (Rwehumbiza *et al,* 1999). This is a simplified version of the catena diagrams 2.6 and 2.7 which were shown above for the respective study regions.

It should be noted that until recently there was little evidence of farmers learning RWH techniques from extension officers. This might have been due to the absence of RWH extension packages in the district agricultural offices, poor training of extension officers in the techniques and the extension workers' orientation to soil and water conservation rather than in RWH. This is an area that this research will address through the development of the Tanzanian DSS which is focused on RWH and its techniques.

In a study carried out by Senkondo *et al* (1999) 76% of respondents questioned during surveys in relation to the adoption of RWH stated that they used at least one of the methods of RWH presented earlier in this chapter. However this still leaves 24% who do not use RWH techniques. There are various constraints that often prevent farmers from applying RWH techniques in Tanzania, these shall now be outlined.

2.7.2 Constraints in the use of RWH

During discussions held with the farmers with regard to RWH technologies, various reasons were given as to why some farmers did not adopt RWH. Table 2.9 lists some of the constraints noted.

Constraints in the use of RWH
- Lack of technical knowledge in RWH - Requires a lot of labour - Location of the farm versus the catchment - Fear of erosion - Lack of cash/capital - Too much runoff - Soil not appropriate - Rain is not enough - Farm flat no runoff

Table 2.9: Constraints in the use of RWH techniques (Rwehumbiza *et al,* 1999; Senkondo *et ai.*, 1999)

Among the reasons, the most frequently mentioned is lack of technical knowledge regarding rainwater harvesting. The specific knowledge that the farmers lack is in the designing of water canals for diverting water from ephemeral streams, as well as knowledge in the control of runoff (Senkondo, 1999).

Labour constraints were mentioned as the second major problem hindering the adoption of RWH. The use of RWH practices requires a substantial amount of labour and/or capital/cash to use and manage runoff. As a result, lack of labour and or capital, affects the capability of the households to undertake RWH. Engagement in casual works (*vibarua*) determined one's wealth status. Casual labourers do not have enough time to work in their own fields and found themselves getting little yield every season and will also have little time to devote to adopting some RWH technologies. According to farmers from Bukangilija village, some poor men do get credit in a form of food and money from rich people well in advance of the rain season with an agreement that they would pay by casual works. Sometimes poor people could easily lose their farms to the rich upon failure to pay back the credit.

As well as determining the constraints and reasons why farmers do not adopt RWH technologies, the farmers who do perform various RWH techniques were asked to detail the problems that they encounter when using RWH technologies. The main problem encountered is the difficulty of water distribution. This is especially the case for those farmers who use diversion channels from ephemeral streams or rivers. In some cases the water may not be enough thereby causing conflicts. The second problem is related to soil erosion and water losses, and sometimes the speed of water in gullies is so high that farmers fail to control it.

2.8 Social sciences and community constraints

Another element, alongside that of RWH, for the development of the Tanzanian DSS is the use of wealth classifications and natural resource use/allocation. A clear understanding of the existing management approaches also needs to be determined to help in developing new techniques or for enhancing the existing management methods.

With regard to the Tanzanian system the concept and application of 'common pool resources' (CPR) management needs to be elucidated. The term CPR was pre-defined (Hatibu and Mahoo, Personal Communication, 2002) as being an important aspect for the proposed Tanzanian DSS. It involves investigating and applying the affects of social barriers and governmental constraints to the allocation of natural resources at a community level.

2.8.1 Common Pool Resources (CPR)

Common pool resources are defined as community owned and managed resources. CPRs can also be defined as those resource management systems in which resource or facilities are subject to individual use but not to individual possession or disposal, where access is controlled and the total rate of consumption varies according to the number of users and the type of use (Williams, 1998; Kumar, 2002).

CPR's managed under common property regimes share two important problems (Quiggin, 1993; Williams, 1998; Lovett *et al*, 2001):

1. Exclusion of resource users is difficult
2. Use of resources by one person subtracts from the welfare of others

The first problem – difficulty of exclusion – arises from several factors including the cost of parcelling or fencing the resource and the cost of designing and enforcing property rights to control access to the resource (Vedeld, 1992; Ostrom, 1995). The second problem – subtractability – creates rivalry between different users. The resource units that one user extracts from a CPR are not available to others. Each user is thus capable of subtracting from the benefits the others derive from a CPR (Ostrom, 1995).

A major problem with CPR's is in preventing "free-riders" from utilising the resources (for example water or nutrients) without contributing to their upkeep.

Perceptions of what constitutes a CPR show remarkable consistency despite factors such as the wide geographical range, broad ethnic affinities of rural people in semi-arid regions and different production systems (pastoral, agro-pastoral and agricultural) (Stevenson, 1991). Perceptions of CPR's are inclusive in nature and comprise rangelands, forests, wildlife, water and agricultural land. With regard to Tanzanian, the resources that are of particular interest are water and agricultural land.

With respect to access, control and rights of usage, CPR's are held under a variety of property-rights regimes (Berkes, 1989; Stevenson, 1991; Ostrom, 1995), including:

- State property
- Communal property
- Private property
- Open Access (non-property) regimes

A few CPR's can be easily classified under a property-rights regime. For example, forests, lakes and riverbanks are often considered as state property and are administered through specialised government agencies (Williams *et al*, 1995 and 1998). For this category of CPRs, various codes and legislative edicts prescribe in considerable detail usufruct rights for different users and penalties for infractions. For many other CPRs, a neat classification is not possible. Furthermore, a given resource may produce flows that are subject to two different property regimes (communal or private) seasonally or over the long term.

Figures 2.20 and 2.21 simplify the principle of 'open-access' to resources. The diagrams demonstrate how resources that are under non-property regimes are open to all potential users; there is no control over their allocation. CPR management tries to add structure to the management and allocation of resources.

According to Stevenson common property is a form of resource management in which a well-delineated group of competing users participates in extraction or use of a jointly held, fugitive resource according to explicitly or implicitly understood rules about who may take how much of the resource' (Stevenson, 1991)

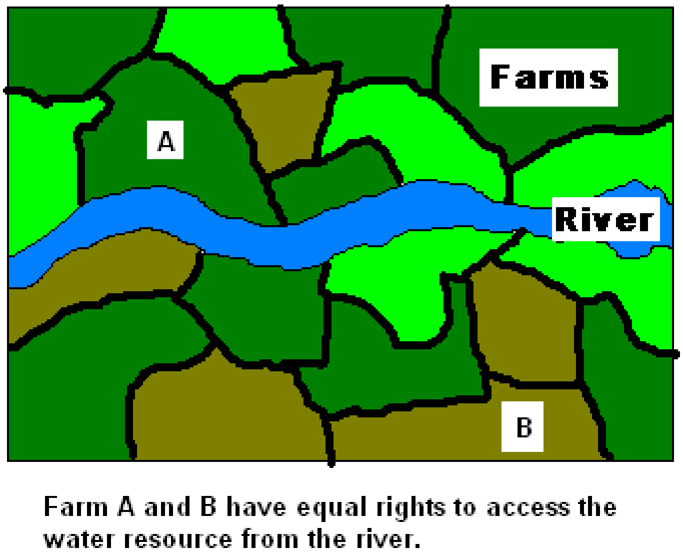


Figure 2.20: **Equal Access to Water Source.** A simple representation of a resource (water from the river) and how it is open to all farms for access (a non-property regime).

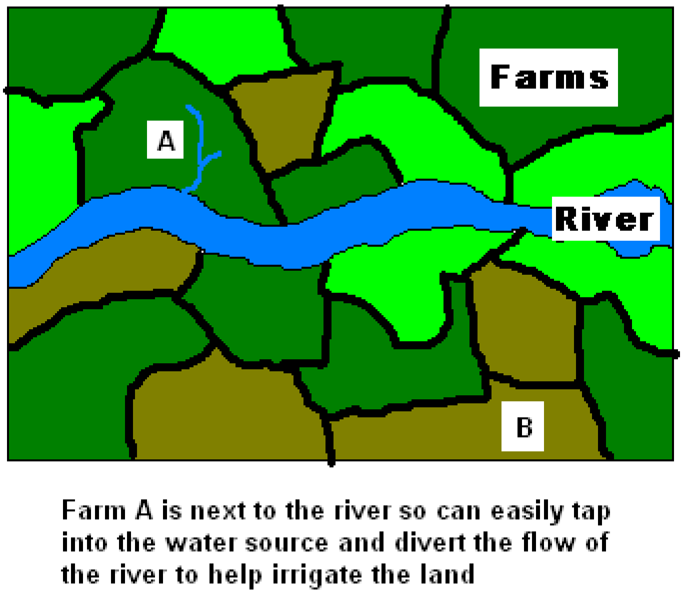


Figure 2.21: <u>Diverting the Water Resource</u>. Farm A has greater access to the resource than farm B (State property regime).

Whereas open access approaches benefit the individual farmer, particularly those with easy access to the resources, CPR tries to instigate an allocation procedure for resources. When decisions are being made there is a transition to CPR management methods as the decisions are likely to affect more than one farmer within a village (Msangi and Kajiru, Personal Communication, 2003). The views of all stakeholders within a community need considering.

CPR may be a beneficial management approach for farms that have only limited resources. The entire local community cooperates in extracting and using the resources, e.g. water and nutrients. However, such resources are not evenly shared among the community members. Under the 'open access' regime the fraction allocated to each farmer is a function of the individual's social status or the position of his land. In contrast, CPR seeks to allocate resources according to a set of rules that are decided upon by the community. These rules need to be perceived as 'fair' for villagers to consider being involved in CPR approaches. In practice richer farmers may benefit most, but if they overexploit the resource too much, the poor will start to break the rules and guidelines that were set out by the community, and the CPR regime will collapse. The implementation of a CPR approach by a local community is often only undertaken if it is recognised to be beneficial in terms of profit, but more importantly beneficial in terms of livelihood sustainability, and is not overtly influenced by social status.

The broad range of common pool resources means that they are central to the majority of rural livelihoods in semi-arid Tanzania. Most of the population in Tanzania can be classified as poor (Hatibu, 2000). Specific local characteristics can be applied for classifying the poor. These include housing, livestock, land and labour. These criteria can help in assigning levels of interest and management for determining the most feasible and sustainable approaches to resource management (Mzirai and Kajiru, Personal Communication, 2003).

Through experience and intrinsic knowledge of farming practices, Tanzanian farmers have learnt to cope with and adapt to differing situations in relation to the availability or lack of natural resources. A sound understanding of the issues that characterise wealth within Tanzania will help in determining how the Tanzanian DSS is to be of assistance to the different levels of user.

The assumption can be made that the poor probably gain less from CPR than the wealthier members of the community (Eggertsson, 1990). For example the poor cannot benefit from rangelands with regard to livestock rearing as they own little, if any, livestock (Ostrom, 1990; NRSP report, 2001). By contrast, if the poor cannot afford irrigation but can use CPR then they benefit more than the rich as the rules set out by the community to utilise CPR aim to benefit all community members.

Family size will influence the need to employ others to work on ones land as most villagers use family labour. However, labour availability (the ability to employ others to work on ones land), rather than access to farmland, constrains the poor from maximising their benefits from CPR. High transaction costs compound this problem.

North (1990) defined transaction costs as the costs of measuring what is traded as well as the costs of monitoring compliance with agreements. In general, there are no precise definitions of these costs, but they are recognized as being the costs associated with establishing contacts, monitoring them and ensuring their compliance (Williamson, 1979; Escobal, 2001). Lovett, 2001 sub-divided these costs into:

- Search and information costs
- Bargaining and decision costs
- Policing and enforcing costs

These costs in Tanzania are at present high because of diverse interests and many users. If transaction costs exceed the benefits of CPR management, then the management strategy will fail or will not be used in the first place.

Various opportunities exist for instigating any improvement in livelihoods. However these face logistical limitations. The options available were determined during a workshop on CPR carried out in Tanzania as part of a NRSP (Natural Resources Systems Programme) in 2001. These options are as follows:

- Increasing livestock ownership
    - Requires equitable access to rangelands
    - Is limited by the carrying capacity of the land, which fluctuates in space and time

- Increasing land availability for agriculture
    - Land quality, availability of water, farm inputs and labour supply will all limit increasing land availability
    - The capacity to use land is a constraint in some areas

- Improving security of employment for poor people
    - Requires the establishment of commercial farming and supportive labour laws
    - May lead to further alienation of the people using CPR

- Improving productivity during dry periods
    - Secure water supplies for irrigation, cattle and pastures could improve productivity
    - Is limited by the availability of water and any increase in productivity requires equitable access

- Encouraging sustainable use of CPR for small scale markets
    - The rural poor rely on CPR to provide meat, wild fruits, wood and medicines for personal consumption and sale
    - The danger is in short term gains at the expense of long term sustainability

The main focus in this study has been upon the management of water and nutrient resources, as well as appropriate land use strategies and agricultural practices.

A common framework for the analysis of CPR issues is described in Figure 2.22.

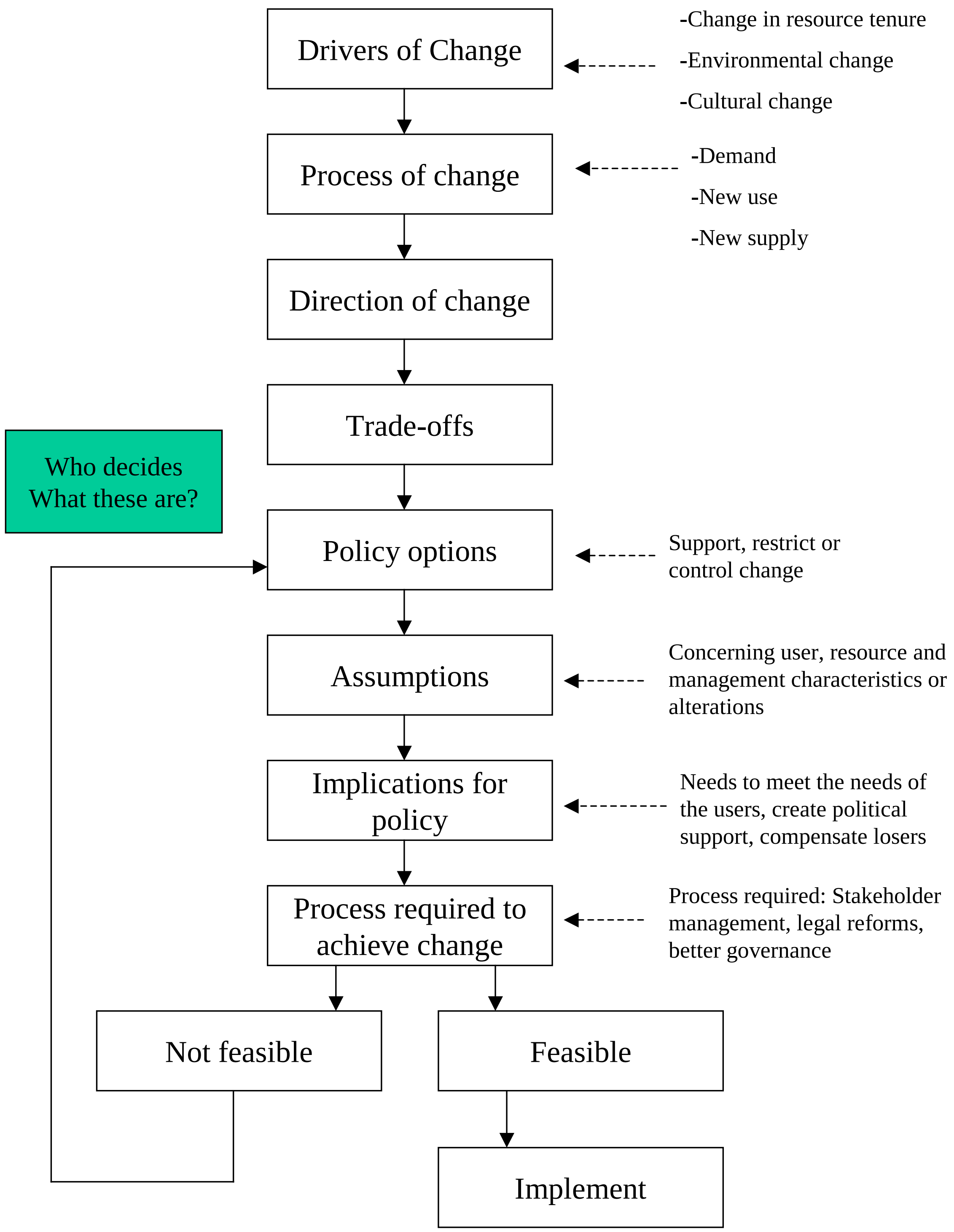


Figure 2.22: **<u>Common framework for the analysis of CPR.</u>** A dynamic model for CPR decision-making. (As derived by NRSP Project SA-R7973, 2001)

Components of this flowchart ultimately need to link with the flowcharts expressed for the development of decision support systems (Figures 3.1 – 3.5). This will help to demonstrate a single process-driven solution for the development of decision support systems for resource management.

2.8.2 An example of CPR considerations

The work of Elinor Ostrom (1990 and 1999) highlights a number of resource and user-related criteria, which determine the likely success of CPR management. These criteria are detailed below.

Salience: This determines the importance of the resource and associated requirements and whether stakeholders agree on this importance.

Common understanding: This evaluates whether stakeholders agree in their understanding of what the resources should be used for. If there is agreement between stakeholders then this is a positive response. There needs to be agreement over resource importance, management and use.

Discount rate: This tests if knowledge or interest is present surrounding the future benefits of resource management for future generations.

Distribution of interests: This evaluates the discerned uses of the resource and the compliance of use between the stakeholders or whether there is a strong distribution of interests.

Trust: This evaluates if different groups/classifications of stakeholders trust each other. If compliance is present then a group effort to management can be applied. This decision is essential for the use of the mathematical predicting tool as it will allow for multiple field scenarios. If little trust is present then a singular approach is required.

Autonomy: This scores compliance and understanding, showing similar traits between villages and catchments.

Prior organisational experience: This evaluates whether similar methods have been tried before and if there is knowledge about techniques that are used in other areas.

Ostrom (1999) has also outlined some considerations that should be adhered to when producing systems that are likely to utilise CPR and how these can be linked to computer systems. A fundamental objective of this study is to link the social situations/issues into the mathematical/computer orientated environment of decision support system development. Table 2.10 details these considerations.

Principle	Explanation
Clearly defined boundaries	Individuals or households with rights to withdraw resource units from the common pool resource and the boundaries of the common pool resource itself are clearly defined
Congruence	a) The distribution of benefits from appropriation rules is roughly proportionate to the costs imposed by provision rules b) Appropriation rules restricting time, place, technology and/or quantity of resource units are related to local conditions
Collective choice arrangements	Most individuals affected by operational rules can participate in modifying rules
Monitoring	Monitors, who actively audit CPR conditions and user behaviours, are accountable to the user and/or the users themselves
Graduated sanctions	Users who violate operational rules are likely to receive graduated sanctions from other users, from officials accountable to these users, or from both.
Conflict resolution mechanisms	Users and their officials have rapid access to low cost, local arenas to resolve conflict among users
Minimal recognition of rights to organise	The rights of users to devise their own institutions are not challenged by external governmental authorities
Nested enterprises	Appropriation, provision, monitoring, enforcement, conflict resolution and governance activities are organised in multiple layers of nested enterprises.

Table 2.10: **CPR considerations.** Principles that should be considered when deciding whether to use CPR within a management strategy (Ostrom, 1999).

2.8.3 CPR objectives and use in Tanzania

The use of CPR is rapidly changing in Tanzania. CPR management in the past is perceived to have been more equitable and to have provided larger scale resource sharing. Changes in land tenure and villagisation have led to restrictions in access to seasonally available resources (Lovett *et al*, 2001). Villagisation in Tanzania influences partitioning of natural resources and the varying governmental laws and by-laws affects the rights of farmers in different villages within the study region. It has been observed that technical solutions are not always the best way forward when addressing this issue due to limited access to technical resources and poor uptake/understanding of the systems expressed by the communities. Projects with the least community participation or consultation are most likely to fail, cause conflicts and have high transaction costs (Lovett *et al*, 2001). Therefore the work carried out in this research for the development of a sound resource management DSS has paid particular attention to the communities for whom the system is being developed. This has helped to ensure clear understanding of requirements for the system for both the scientific developers and the farmers. Constant consultation and communication with partners in Tanzania has been of the utmost importance throughout this research. Awareness towards this research in Tanzania has helped bring about its successful completion and execution.

It is necessary to have a sound understanding of where qualitative approaches fit within the modelling process to see how they can be linked within the predominantly quantitative world of models. Also an understanding of the social aspects and implications for Tanzanian agricultural management will help to highlight how these approaches can be used to benefit the proposed decision support system.

2.8.3.1 Villagisation in Tanzania

Villagisation has briefly been mentioned above however, it is an important concept that requires further details to be expressed as it is of influence to communities living in Tanzania.

Tanzania’s resettlement programme, known as villagisation took place between 1970 and 1976, and it was unique in that it involved the largest number of people in the history of resettlements in the Third World.

In his 1968 policy statement, *Socialism and Rural Development*, Nyerere expanded on the objective of building socialism in Tanzania based on the traditional family values of mutual respect, sharing of basic goods and services held in common, and the obligation of everybody to work (Komba 1995). His famous concept of *ujamaa* (which means 'familyhood' in Swahili) refers to 'socialism in the villages'. The villages would be "rural economic and social communities where people live together and work together for the good of all" (Nyerere 1968).

Villagisation began as a voluntary programme in Tanzania, although government officials took advantage of unseasonal floods in 1969 to persuade people to move. The lure of social services attracted people to villages. When Nyerere learned that his officials tended to use force to start villages, he said: "No one can be forced into an *ujamaa* village. . .then it will no longer be an *ujamaa* village" (Coulson 1982). However, the tune eventually changed. Nyerere and his government felt that villagisation was proceeding too slowly; their promise to transform rural areas might lose credibility.

Forced villagisation in Tanzania happened through 'operations', and several writers emphasise the appropriateness of the military terminology. Operations were aimed at the massive villagisation of people in a short time; in 1973, Nyerere made it compulsory to live in villages in three years (Raikes 1978).

Villagisation affected pastoralists in Tanzania. A recent study of its impact (Lane 1998) argues that whatever the potential merit of providing improved services to rural populations, the settlement of pastoralists poses serious challenges to "common property resources management". The Barabaig herders who settled did so out of poverty and had no choice but to limit their migration to the distance their herds could travel to and from the homestead in one day. The concentration of animals in villages had a negative ecological impact and led to a further decline in levels of production (Lane 1998).

Ironically urbanisation in Tanzania increased faster than almost anywhere else in the world in the 1970s (O'Connor 1988). People's dissatisfaction with the villagisation programme led them to continue to the towns. In particular, villagisation reduced people's freedom and concentrated power and control in the hands of local party leaders, which may have been an incentive for others to move to town. Also, people had been wrenched from the land where they had always lived; once they were on the road, they often decided to move further to the city.

The problems arising from villagisation can be divided into those derived from the way villagisation was implemented and those arising from the actual experience of living in the new villages. In the first category fall the use of force which fostered resentment among rural populations, the lack of adequate planning, the lack of consultation with people involved, the speed with which villagisation was often carried out, and the lack of services which felt to people like broken promises. The second category includes problems relating to the physical location of the villages, especially their distance from the fields, in terms of walking to them and protecting them from vermin and theft, and lack of water and fuelwood. It also includes adverse effects on the environment and particularly on the land used for farming or grazing, the increased risk of communicable diseases, and adverse effects on social equity or community harmony.

Potential benefits from villagisations include the increased access to service provision in some areas, the more sociable and often safer environment of a village community, and the chance to develop some form of meaningful village government. The perception of benefits was sometimes generational, with young people having a greater appreciation for the social and educational opportunities offered by the villages. Proximity to roads and transport afforded greater mobility.

For examples of costs and benefits of villagisation in Tanzania refer to Table 1 in Appendix 4

The above country-specific and issue-based discussion has drawn out several key messages about villagisation. First of all, while the policy of villagisation can in some cases be a feasible solution to a country's problems, the implementation, if done in certain ways, can be extremely difficult and painful for the rural dwellers involved. Some ways to avoid this have emerged. One is to place far greater importance on planning. There is a great need for open communication with the population about agenda, timetables, and visions. This openness would ideally go beyond keeping people informed and would get them involved, so that they would participate in a process which will, after all, change their lives.

2.9 How will this research address these issues?

A fundamental aim of this research is to increase the awareness of farmers to different agricultural management options – related to RWH and soil fertility. Alongside this, the study aims to highlight the potential benefits of applying community based management options as opposed to working on a single farmer basis.

The DSS that is to be developed will illustrate potential options that are available to the farmers and communities. These options will be dependent upon the information supplied to the management tool, and hence will be very much user orientated options.

The developed DSS will not be able to specifically solve the constraints of performing RWH techniques. It is to be seen as a tool that can help invoke discussions on the topic of RWH management and potentially propose options for alternative agricultural management practices that may benefit the farmers or community.

As can be seen from Table 2.9, the majority of the constraints affecting the adoption of RWH technologies are associated with lack of knowledge of the technologies and poor resource management. By using the Tanzanian DSS and the outcomes from this research, the farmers, extension officers and agricultural scientists will be able to increase awareness towards RWH technologies and improved resource management options.

To aid in improving the technical knowledge of both farmers and extension workers with regard to RWH technologies, focus groups will be held and run by agricultural scientists, whereby knowledge of the technologies – particularly those associated with the developed DSS - will be disseminated and discussed. Literature and examples will be presented to the focus group participants to help the learning process and a questions and answers session should be held (Kajiru and Mzirai, Personal communication, 2002).

With regard to the resource constraints of labour, lack of cash/capital and inadequate rainfall, the prospect of looking at community based management approaches should be considered and discussed with the farmers involved. The application of the Tanzanian DSS will help to tackle these issues by allowing the extension officers to input data provided by the farmers surrounding their existing agricultural practices. Concerns over whether or not a farmer's soil type is suitable for RWH technologies can be alleviated by referring to the notes that detail the different soil types present in the study areas. An understanding of the soil type and the potential management strategies and agricultural practices that can be performed on the soil type will help the farmers to understand the potential of their soil type. Location of farms in relation to water resources will always be an issue for the farmers. Revised and improved methods of collection and allocation of water resources may help to benefit those situated further from the resource. Once again, this is a community based decision and is something that will be raised during discussions with the farmers when utilising the outcomes of this research.

Issues related to runoff being too high or too little can be tackled by the introduction and sound management/application of the RWH technologies that have been discussed earlier in this chapter. However, once again solutions to the issue lies in being able to raise farmers' awareness and understanding of the possibilities and improvements that can be achieved through applying RWH technologies.

It must, however, be noted that in some cases it may not be the best decision to apply RWH technologies, and the DSS will help generate discussions regarding alternative solutions. It is also ultimately up to the farmer or community as to whether they wish to adopt the proposed solutions from this research and the Tanzanian DSS.

The above description of the study catchments and the RWH options available help to give focus to the development of the DSS, to ensure it is suitable for the local target community and robust enough for general principles to be developed and tested. It is now necessary to highlight and discuss the various participants involved in the research and their underlying roles that will be alluded to throughout this thesis.

2.10 User groups

The term "user" is a loose one and requires further verification. Within this research and the development of the Tanzanian DSS there were various levels of users. The levels involved were:

- **Development user team –** these are the people who are involved in collecting the data for the development of the system and those who will actually carry out the programming and system development and execution.
- **End users –** these are the extension officers and scientific researchers in the study regions who will work with the beneficiaries of the system to utilise the functions within the system and research.
- **Test subjects –** these are the farmers in the study regions for whom the system is being developed and the research is being carried out.
- **Beneficiaries –** these are the farmers of different social status within the study regions who will ultimately benefit from the system(s) being developed and this research.

Each of these user groups shall now be further explained and specific examples of their involvement within the research expressed.

2.10.1 Development User Team

The development user team consists of the researchers on this project based both in Nottingham and Tanzania.

The expertise brought to the project from the Tanzanian researchers is in the agricultural management techniques, with particular focus on RWH. They also possess the knowledge and understanding to help with the profiling of the Tanzanian farmers which will aid the team in Nottingham to build up a better picture of the situation in Tanzania. The Tanzanian development team will have to liaise with the other user groups based in Tanzania to help ensure the continuation of the project and the acquirement of relevant information for DSS development. Alongside their extensive knowledge of the project being undertaken, a fundamental role of the development user team in Tanzania is to act as the liaison point between the developers. Therefore a sound communication strategy will be developed. This is of particular importance as the team from Nottingham will not be spending much time in Tanzania collecting data etc, all data and information will be provided for the development team in Nottingham by proxy from the team in Tanzania.

The development team in Nottingham is those individuals who will take the information provided by the team in Tanzania and use it for producing the DSS. Expertise lies in the fields of agricultural sciences, social sciences and computer modelling. These three fields are fundamental for the development of the Tanzanian DSS.

Communication within this user group is essential to ensure the development of the Tanzanian DSS.

2.10.2 End Users

The end users of the developed DSS are extension officers and agricultural scientists. These individuals will have worked closely with the development team during the production of the tool to ensure that they understand its functionality fully. Their input to the development of the tool is also pivotal as this will aid in the dissemination and utilisation of the tool by the beneficiaries. They will also possess knowledge of agricultural management techniques and have a sound understanding of the needs of the individual farmers and communities in Tanzania.

The end users act as the link between the development team and the end beneficiaries of the system. The extension officers will utilise the developed tool in conjunction with the beneficiaries and the information provided by them. The development team will have trained the extension officers in how to use the tools to ensure suitable outcomes are obtained. The extension officers are the main communication point between beneficiaries and potential management options determined by the use of the developed Tanzanian DSS. This ultimately is their main role within this research, to use the DSS and communicate the results to the beneficiaries.

2.10.3 Test Subjects

During the development of the Tanzanian DSS it is important that systems are tested and verified. To enable this to happen, test subjects are required for determining the suitability of relationships, testing theories and testing the DSS model.

Within this research there are two levels of test subjects. The first are the extension officers who will have to work closely with the development team with regard to the relationship building within the DSS and the functionality of the tool. These are the individuals who will be using the tool, and therefore they need to be able to fully understand its uses. The second set of test subjects are the actual farmers in Tanzania. Before the developed DSS can go 'live' the tool will need to be demonstrated to the farmers in the field and tested using 'real' data and scenarios. This will ensure that the outputs from the DSS are feasible and understandable both to the extension officers, but more importantly for the farmers for whom the system has been designed. Testing of the DSS will take place via participatory methods – meetings and focus groups held with villagers.

2.10.4 Beneficiaries

The beneficiaries are those individuals or groups who will benefit from the system(s) being developed during this research. The farmers in the two study regions (Maswa and WPLL) are the ultimate beneficiaries. But beyond them, this research also aims to be able to be seen as the building blocks in a field of systems development that looks at integrating both quantitative and qualitative data types. Therefore other beneficiaries of this research could include other researchers interested in systems development, as the ideas and theories expressed in this research could be built on in the future.

2.11 A question of positionality

An important issue that should be considered when carrying out this sort of research is that of 'positionality' – having an understanding of where the data is coming from for the research, who and where it is being analysed and an understanding of the relationships between the researchers and the subjects.

Positionality is not simply a trendy issue that must be referred to in passing, nor simply a personal one that authors allow to pinch them from time to time in the privacy of their office when they question their motives in promoting the findings they do (Limb *et al*, 2001). Positionality is rather an issue for public debate. Recognition of motivation, differences of position and an awareness of personal reasons for the promotion of particular issues can all be put to valuable use to piece together a more complete picture of society (Limb *et al*, 2001).

It is crucial in any research that positionality is considered and what it might mean in relation to the ways in which the research is carried out, and how the people who are contributing towards the research perceive the primary research team (for example the Nottingham team).

Limb and Dwyer (2001) explain how positionality implies aspects such as race and gender, but also one's class experiences, education, sexuality, age and ableness. All these have a bearing on who we are, how our identities are formed and how we do our research. It can be said that we are not neutral scientific observers, untouched by the emotional and political contexts of places where research is carried out. Limb and Dwyer (2001) state "we are amalgams of our experiences and these will play different roles at different times".

Skelton (2001) expresses how cross-cultural research is difficult, particularly if "we think through and acknowledge the complexities, sensitivities and dilemmas that are implicated within it, but that does not mean we should abandon doing it". What it does mean, though, is that researchers should constantly think about what they are doing and why they are doing it and how the research might affect other people.

Positionality plays an important role in this research as the majority of the DSS development will be taking place in the United Kingdom, away from the end users. The development team in the UK come from a very different background both socially and culturally to the end beneficiaries of the DSS. This may prove to be a benefit or a hindrance to the development of the DSS, and shall be discussed in later chapters of this thesis. With this in mind it has been important to establish good communication links with the development team out in Tanzania to help aid the production of the DSS.

2.12 Limitation in data collection

The concept of positionality has highlighted the fact that the majority of the data being collected for the development of the Tanzanian DSS is being provided by proxy. Such that the team in Tanzania will be collecting the data and then disseminating this to the team in Nottingham to use for the development of the DSS. Funding during this research was not made available for additional travel and experimental work to be carried out by the Nottingham team in Tanzania. The Nottingham team were reliant on the information provided by the team in Tanzania, hence it can be said that the DSS is only as good as the information provided by the agricultural scientists in Tanzania. With this in mind, it was important that continual communication was held between the development teams to ensure the progress of this research.

Developments in qualitative research methods have attempted to address shortfalls in distant, scientific research process in the field through the increased involvement of the researched at all stages of the research project. Emancipatory, collaborative and unexploitative research has generally been seen as synonymous with qualitative methods (McDowell, 1992; Stone et al, 1996). In a collaborative research project it is argued that the researcher and researched come to an understanding of what is taking place around them to develop a sense of trust to share their experience in an atmosphere of safety and support. Commonalities between the researcher and researched can be recognised and become part of a mutual exchange of views (McDowell, 1992).

It can be concluded that for this type of research into the development of DSSs that incorporate both quantitative and qualitative data types, it is important to have a sound grasp of the user groups involved in the research and to understand the importance of the positionality of the researchers compared to the researched. These concerns will be drawn on further within this research.

2.12.1 Communication Strategy

To help overcome some of the issues with possitionality and the collection of data it was necessary to develop a sound communication strategy between partners based in Tanzania (SUA Team) and the team in Nottingham. Project reports and data had to be distributed amongst all team members. Constant communication via the use of Email on a weekly basis between the DSS development team helped to ensure the progression of the development of the Tanzanian DSS. A quarterly reporting cycle was devised whereby both teams could report on the research that they had been carrying out. Examples of these reports can be viewed within Appendix Six. Visits were also set up whereby members of the SUA team visited Nottingham to work 'hands on' on the project. Five meetings in total were set up whereby members from Nottingham and Tanzania were able to work face to face on the development of the DSS. The communication via Email was a two-way process such that questions were asked and answered by both teams.

2.13 The proposed solution

As already mentioned in the introduction and within this chapter, the aim of this research is to produce a decision support system (DSS) that focuses on agricultural management techniques (particularly those related to water resources) in Tanzania. The DSS will benefit both individual farmers and groups of farmers – the community. Two study areas in Tanzania have been outlined in this chapter – Maswa and WPLL. These areas will act as the study regions and test areas for any proposed solution.

The DSS will be developed through collaboration between the team of researchers at The University of Nottingham in the UK and the team based at Sokoine University of Agriculture in Tanzania.

The outputs expressed by the Tanzanian DSS should be seen as options to agricultural management and should not be seen as the final answer. The DSS should be used more as a starting point to instigate discussions between farmers and communities and the extension officers and scientists in Tanzania. Decisions have to be made through discussions as to whether to adopt the proposed solutions outputted by the DSS device. These decisions cannot be made solely by a computerised model. Human perceptions and intervention must also be considered.

Chapters 3, 4 and 5 discuss in greater depth the proposed solution and the development of the Tanzanian DSS.

2.14 Summary

This chapter has outlined the issues that are faced by the farmers in the different study regions with regard to RWH, CPR and agricultural management, and how the production of the Tanzanian DSS is a step in the right direction for proposing new management options for individual farmers and communities.

The context of the research has been expressed focusing on the concept of RWH. The catchment areas of Maswa and WPLL have been described. This understanding of the subject matter for research is essential in ensuring a feasible solution can be derived for the research problem, that of improving the management of water resources in Tanzania. Alongside this, it is also necessary to be aware of the different levels of end users, during the production of any form of computerised system. This will ultimately influence the capabilities of the tool and the future dissemination and extrapolation of the tool.

This research focuses on the difficulties observed by farmers in Tanzania with respect to agricultural management strategies. The primary concern is that of water management. It is likely that the concepts, theories and ideas expressed within this thesis could be extrapolated to other semi-arid regions of the world. The Tanzanian scenario provides the building blocks for an area of systems development that incorporates both quantitative and qualitative data types, an area that future systems development studies should consider.

Now that the study area and concept of rainwater harvesting have been discussed, the next step is to describe the approaches adopted for the development of the proposed solution for this research – the development of the Tanzanian DSS.

<u>Chapter Three</u>

SYSTEMS DEVELOPMENT, ANALYSIS AND MODELLING

3.0 Focus of Chapter Three

The focus of this chapter is to highlight and discuss the different approaches that can be used for the development of Decision Support Systems (DSSs). Quantitative and qualitative approaches are described. The chapter concludes by detailing the single systems development approach that was developed during this research and how it was applied to the development of the Tanzanian DSS for RWH management.

3.1 Existing models and methodologies

Before agreeing how to design the DSS, it was necessary to understand the current situation in Tanzania in relation to the use and implementation of RWH systems and management tools. Also required is an understanding of the importance of decision support tools and models and how their application can be of benefit for agricultural management.

3.1.1 What is a decision support system?

A DSS is a system under the control of one or more decision makers that assists in the activity of decision-making. This is achieved by providing an organised set of tools, which are intended to impose structure on portions of the decision making situation, and ultimately improve the effectiveness of the decision outcome (Guariso *et al*, 1989; Sprague *et al*, 1996; Galitz, 1997; Burckhard *et al*, 1999; Deitel *et al*, 1999; Marakas, 1998, 2002, 2003).

3.1.2 What is a crop model?

Sinclair and Seligman (1996) state that a crop model is the “dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers”.

The focus of most models is on one data type – either quantitative or qualitative. The majority of models utilise numerical "quantitative" data to help provide solutions (Sprague *et al*, 1993 and 1996; Matthews and Stephens, 2002). Few systems try to tackle the complexities of "qualitative" human perceptions and views towards management strategies (Moulin, 1994; Kurzweil, 1999). Although, bridging the gap between qualitative and quantitative data requires considerable thought (Bryman, 1988 and 2000; Marshland *et al*, 2001), systems and approaches are being developed that try to provide a quantitative basis to the qualitative information (Ostrom, 1999). These so called DSSs may make use of participatory rural appraisal (PRA) techniques (Chambers, 1981 and 1992) to help quantify the views of the individuals for whom the system has been developed.

3.2 Current Situation for models

Until recently, limited effort has been directed to the development of agricultural management tools based upon simulation models (Moulin, 1994; Kebreab *et al*, 2000; Jakeman *et al*, 2003). However, the adoption, development and use of crop models has now been recognised as a feasible and cost-effective tool for agricultural research (Matthews and Stephens, 2002). These systems have the capacity to make predictions based upon the specific environmental and physical parameters outlined. Present day investigations by social scientists such as Elinor Ostrom, into the development of criteria that could fundamentally be utilised within DSSs has brought about a greater understanding of how the human aspect of modelling and decision-making can be incorporated within computer systems.

Agricultural enterprises are generally highly complex since farmers' activities are strongly affected by the external environment as well as by their own goals and culture. In managing these activities, farmers are faced with an enormous range of decisions throughout the year.

A decision implies a clear-cut resolution of a problem, yet the process of reaching a decision can be anything but straightforward. Many factors have to be considered and we usually rely on intuition and experience to resolve issues. This assumption is apparent in the context of the Tanzanian agricultural scenario. Therefore, agricultural systems highlight a key area whereby the application of models and decision support tools would be beneficial. DSSs are designed to help farmers make decisions by evaluating outcomes of alternative action in the light of available information. Consequently *"there must be a problem before a decision can be made"*.

3.3 The origin of models

The origin, purpose and use of models were as research tools and they have proved beneficial for research processes (Matthews *et al*, 2002), examples of which will be expressed shortly. Greater problems are being solved by the use of models and the inclusion of models in DSSs, as they have various uses (Sinclair *et al*, 1996; Kebreab *et al*, 2000; Marakas, 2000 and 2003), including:

- Identification of gaps in our knowledge
- Generation and testing of hypotheses
- Help in the design of experiments
- Sensitivity analysis – the determination of the most influential parameters of a system
- Provision of a medium for better communication between researchers
- Bringing researchers together to solve common problems

3.4 Examples of models

Matthews and Stephens (2002) have written many papers on how models can be of benefit to agricultural management as well as expressing how in the present day these models can and are being incorporated within decision support tools.

Four examples of crop production models described by Matthews and Stephens (2002) are:

1. PARCH
2. PARCHED-THIRST - (**P**redicting **A**rable **R**esource **C**apture in **H**ostile **E**nvironments **D**uring **T**he **H**arvesting of **I**ncident **R**ainfall in the **S**emi-arid **T**ropics)
3. EMERGE
4. SWEAT

PARCH and PARCHED-THIRST (Gowing *et al*, 2001) are the most relevant tools as a basis for this study as they provide a quantitative evaluation of resource capture and utilisation that can be used to develop a DSS. Also, as these models are currently being applied in Tanzania by the extension officers affiliated to Sokoine University their continued use provides consistency with existing activities.

3.4.1 PARCH

The PARCH model was developed by Bradley and Crout from 1990-1996 and uses daily time steps to simulate crop growth. On each day, the resources (light and water) are "captured" and "converted" by a given crop into assimilated dry matter. The availability of each resource and the ability of the crop to capture them, determines whether the growth of the crop is light or water limited. Crop water balance simulation is a key component of PARCH. The water use efficiency parameter links the water demand calculated from the potential dry matter production (driven by intercepted solar radiation) with the water uptake by the crop and is crucial to the reliable prediction of final dry matter production and yield.

3.4.2 PARCHED-THIRST

The development of the PARCHED-THIRST (PT) model was started in 1992 (Crout and Azam-Ali, 1996). PT was developed to simulate the key processes influencing the performance of rainwater harvesting systems and uses the PARCH model in order to predict yields. Rainwater harvesting is defined as the collection of runoff as sheet flow from an adjacent catchment area into a cropped area without storage other than in the cropped area (PT online user manual, accessed 2002). The model therefore assumes that there are two distinct areas of the field in which one part is a catchment (runoff) area and the other a cropped (runon) area. Daily rainfall and other agro-meteorological data are used within PT. The model includes a stochastic weather generator for the extension of historical data to provide simulation of long-term performance. A rainfall disaggregator can convert the rainfall data into an intensity value – mm of rain per hour. The rainfall-runoff process is simulated as an infiltration excess. PT adds soil water redistribution and crop growth simulation routines to enhance its capabilities beyond those of the PARCH model.

3.4.3 SWEAT

The SWEAT model was developed from 1991-1995 and simulates detailed diurnal time courses of evaporation processes from the soil surface or from the canopy, and the water or temperature status of the soil close to the soil surface. Although the model also simulates the effect of root water uptake and transpiration from a sparse canopy, vegetation was not considered (Daamen and Simmonds, 1994).

SWEAT uses hourly data of air temperature, humidity, windspeed and radiation. It requires information about the soil (texture, water retention and hydraulic conductivity) and, if present, the crop (height, leaf area index and distribution of root length density).

The SWEAT model simulates a one-dimensional soil profile by considering the soil as a series of homogenous layers with various thickness (Daamen and Simmonds, 1994).

3.4.4 EMERGE

The EMERGE model and associated research was conducted in 1992-1996. EMERGE was developed to simulate the germination, seedling growth, emergence, and establishment of a population of seeds as a function of soil physical conditions.

EMERGE consists of two parts: SWEAT as described above and GEMA, a model that uses the soil temperature and matric potential predicted from SWEAT to estimate duration from sowing to germination, shoot growth, and emergence for a population of 100 seeds.

GEMA calculates the seed mass lost by respiration after germination had begun. If the seed tates too long to emerge, it may fail because the seed runs out of its reserves. Both soil hardening and soil drying can result in failed emergence, as can lethal soil temperature at the shoot meristem (Mullins *et al*., 1996).

3.5 Development of strategies for the production of agricultural DSSs

Before any system for improving agricultural management can be developed, a specific structure or strategy should be applied to aid the development process. There is no single approach used for the development of DSSs. Decision making strategies used by individuals vary with the amount of information they are presented with and with the sequence in which they obtain it. The process is also affected by the amount of pressure that the farmers are under to reach a decision, for example due to time or importance of the outcomes.

Using agriculture as a reference point, there are three types of in-farm management decisions that need to be considered.

1. Operational decisions
2. Tactical decisions
3. Strategic decisions

Operational and tactical decisions tend to be ‘actions’, while strategic decisions tend to be related to ‘planning’ (France *et al*, 1984; Kourik, 1986; Matthews, 2000 and 2002).

There are also three levels of farm system that have been identified that relate to the type of modelling approach used (Tsuji *et al*, 1998; Matthews *et al*, 2002).

1. Unconstrained – models that focus on the ecological components only
2. Resource constrained – models that incorporate the economic components in addition to the unconstrained level. They may include simple decision-making processes
3. Adaptive – models which incorporate the social component in addition to the resource constrained level

For the production of the Tanzanian DSS the system based upon the *adaptive* approach will be utilised – this looks at resource capture and utilisation by crops, along with social factors.

To develop a robust and applicable DSS a logical structure is required that is transparent and an approach that is amenable to subsequent improvements. Various strategies and frameworks are presented in the literature – e.g. the Systems Development Cycle (Anon, 1988b) and those expressed by Marakas (1998 and 2003) e.g. Simon's model (Simon, 1960) – both of which have similar characteristics in terms of application.

The following examples of development processes highlight the common similarities. In summary, the processes have a start point that involves the analysis of existing methods. This is followed by determining new or improved management approaches, and finishes with the development and application of the new approaches. These simple stages are highlighted predominantly by the SHARES (SHAred RESources) approach as devised by Stroosnijder *et al* (2001).

Examples of decision support strategies include:

- Systems development project management guide
- Marakas approach – phases of development
- Simon's model
- SHARES approach

The methods above share common traits, which are summarised below. An aim of this project is to use elements of these approaches to formulate a single and more generic strategy for the development of decision support systems.

The **Systems Development Project Management Guide** (Anon, 1988) provides a generic framework for the development of decision support systems. (See Figure 3.1).

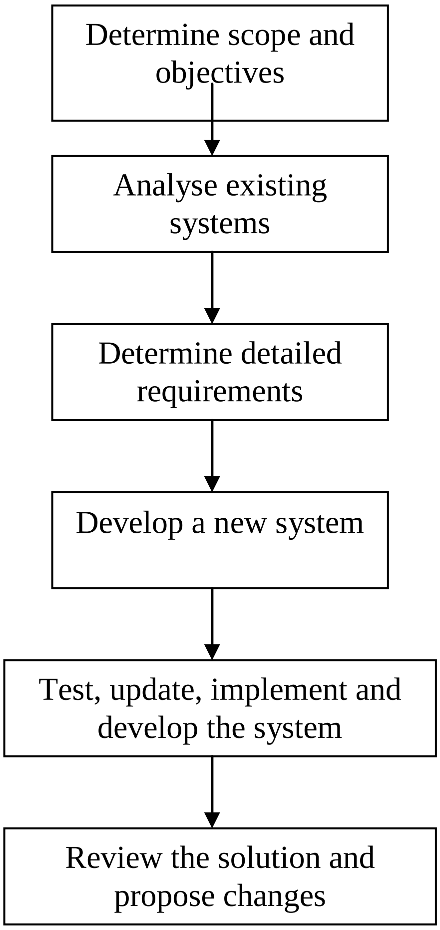


Figure 3.1: **Framework for the development of DSSs** (Anon, 1988)

The development of the DSS should follow a structured development 'life cycle'. This is a further expansion of the above diagram and can be illustrated by Figure 3.2

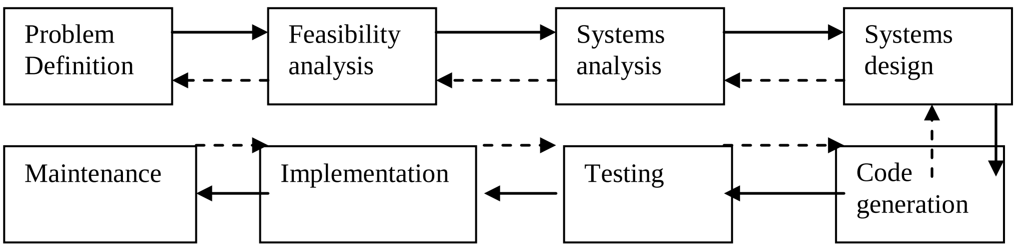


Figure 3.2: **Development life cycle** for the production of a DSS (Anon, 1988b)

Decision-making is a structured process. Figure 3.3 demonstrates this.

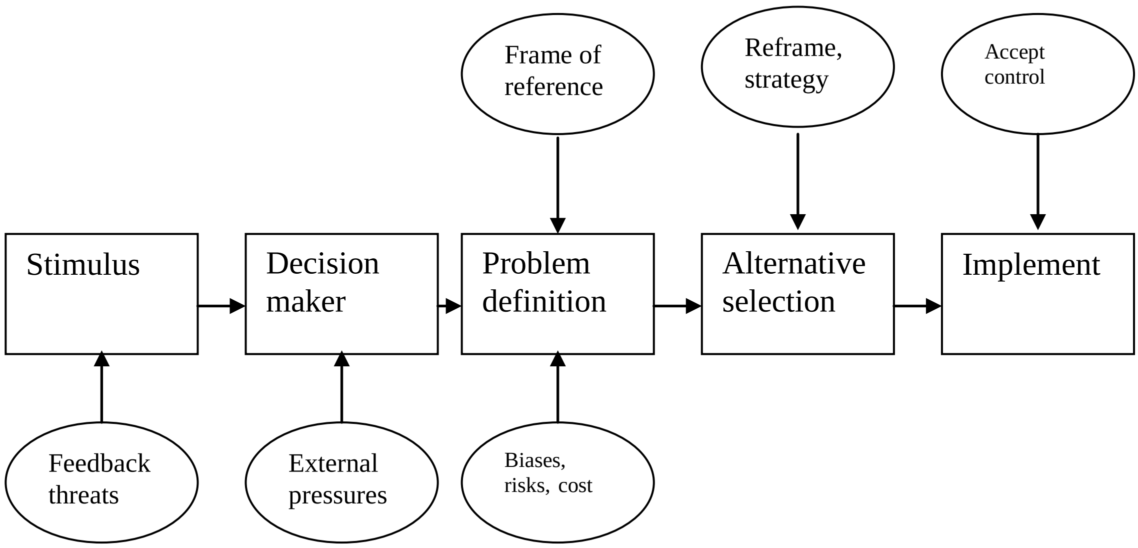


Figure 3.3: **Structured process of decision-making**. (Adapted from Marakas, 1998 and 2003).

Simon's model (Marakas, 2003) recognises that the user of the system has some understanding of the processes involved within the model and the purpose behind its use. There is an element of prior knowledge of the system from the user, such that they are able to discern whether or not the outcome from the model is feasible (Rizzoli *et al*, 1997). Elements of computer aided design (CAD) need to be applied to the design of the system to help ensure the user-interface of the DSS is suitable and workable. Areas of interest include the layout, text and graphics, and aesthetics – colour, style etc.

From the system, a series of solutions should be offered to allow the user the ability to choose the approach that they feel is best. This choice will occur before the implementation of any improved management strategy is undertaken. Before and after implementing a proposed strategy it is important to carry out a feasibility analysis on the approach. This will help in determining any modifications that are required. Then the decision-making process can start again.

The information stated above is illustrated in diagrammatical form in Figure 3.4.

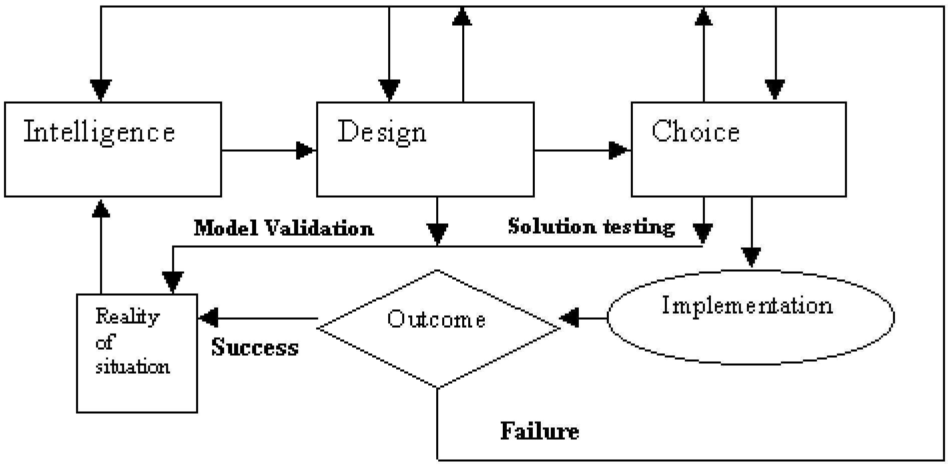


Figure 3.4: **Simon's model for DSS development** adapted from Marakas (2003).

Simon's model is a good example of an approach for DSS development that focuses on the application of quantitative methodologies, information and testing.

Qualitative researchers also possess approaches for the development of models and for determining management decisions. Although these methods follow a structured flow, some scientists deem them to be less structured than the quantitative approaches to modelling (Bryman, 2000), primarily due to the extensive interaction and questioning of the potential users of the system.

One example of DSS development used for qualitative research is that outlined by Stroosnijder (2001) under the title of **SHARES**. This method is split into three distinct parts:

1. Descriptive phase
2. Explorative phase
3. Planning phase

Each phase shall now be expanded upon stating the aim of the phase and the expected outcome.

Descriptive Phase

- Aim: Characterisation of present situation
- Output: A description of the present situation and potential solutions utilising existing technologies

Explorative Phase

- Aim: Explore medium term options for development
- Output: A structured matrix describing optima for various object functions

Planning Phase

- Aim: To analyse ways and means to bridge the gap between the present situation and potential solutions
- Expected Output: A clear indication of how this can actually be realised

SHARES approaches model development in a holistic fashion, while still remaining relatively simple. SHARES can serve as an intermediary tool between scientists and extension officers working in the field who have close relationships with the potential beneficiaries of any developed systems. Principally the approach used to instigate this model is linear programming as the model undergoes linear processes.

These examples of quantitative and qualitative approaches to modelling can now be discussed in relation to integrating them to form a single development strategy.

3.6 Development of the Single Strategy for DSS development

3.6.1 Introduction

Frameworks or 'conceptual models' are often crucial to the understanding of a new or complex subject such as the decision-making process involved in choosing an agricultural management technique to apply. A framework that identifies parts of a topic and how they interrelate, allows researchers to extend and expand their mental model and extrapolate additional understandings (Sprague and Watson, 1996).

This section of chapter three goes into the decisions that were made when developing the single strategy for integrating quantitative and qualitative data types and methods for the production of the Tanzanian DSS.

3.7 Systems Analysis and Strategy Development

Kebreab and France (2000) describe ten points that should be considered when undertaking modelling and systems development work in the semi-arid tropics. Table 3.1 details these ten points.

Guideline	Notes
Objectives	These should be clearly stated, and information and justification on the need for the system to be developed should be given. The intended users of the system and how they might use the system need stating. Potential users should be involved in model development.
Dissemination	Dissemination pathways should be planned in advance. Various people are involved in this process – research and extension scientists, social scientists and the end users. It is important to keep these links, as it will help in the uptake of any developed system. Research funding should also be spent on dissemination as well as research.
Collaboration with an institution and, if possible, people in the target country	It is helpful to have links with local institutions, especially if they are involved in or interested in the system being developed. This link will help with the dissemination of the system and any follow up research.
Collaboration among system developers	A systems modelling group should be formed as this will help to keep people informed of the progression of the systems development.
Users' database	Potential users in national research units, universities and non-governmental organisations need to be identified and a database of people likely to benefit from the system created.
Workshop and training	Evaluation of the system and its adaptation to the local environment should be carried out by organising workshops that involve all the key individuals identified. This will be part of the dissemination process and helps to encourage enthusiasm in the system and helps to improve confidence in the model through regular training programmes.
Technical assistance	A member of the systems development team should act as a contact person for users, if any problems arise.
Follow-up	It is important to follow the progress of the system among users. This will help the system to become established.
Evaluation	Evaluation of uptake and impact of systems should be carried out periodically. Systems can become obsolete in a relatively short period of time – and it may be necessary to improve the system with any advances in technology.
Risk assessment	Users of the systems need to be aware of the risks involved in following a particular management strategy. It may be necessary to build some sort of 'risk' facility into the system related to the ultimate purpose of the system in the eyes of the user.

Table 3.1: **Development of a management system.** Ten points of consideration when developing a management system (adapted from Kebreab, 2000).

As with the process set up by Anon (1988, 1988b), these ten points follow a simple flow based upon identifying a problem, discussing and researching this, and finally determining a solution and testing this outcome. These guidelines are generic and can be applied to a range of scientific research processes.

3.8 DSS Components

Sprague (1996) utilises the 'dialog, data, and models (DDM)' paradigm (Figure 3.5) to describe the component parts of a DSS.

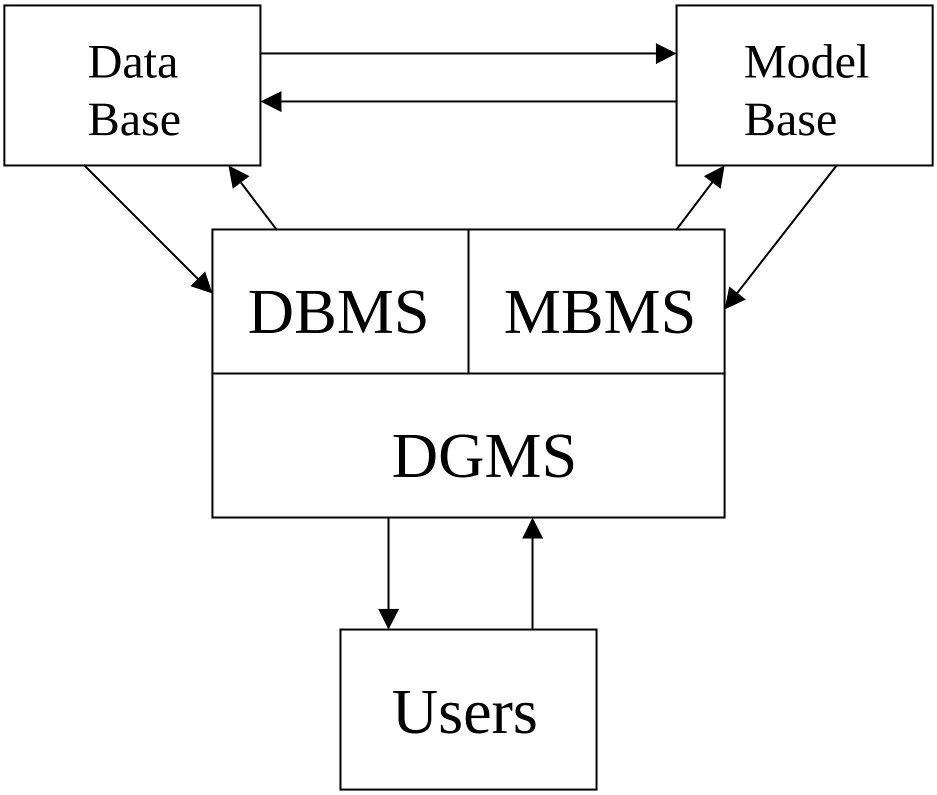


Figure 3.5: **The 'dialog, data, and models (DDM)' paradigm**. DBMS – database management system, MBMS – model base management system, DGMS – dialog generation management system (Sprague and Carlson, 1982)

The standard description of a DSS is an interactive computer system that assists decision makers to solve unstructured (or loosely structured) problems. Thus, the intention is that they can be applied to a broad class of problem, each instance of which is specified through a dialogue between the DSS and the manager (user).

It can be said that DSSs combine numerical models (simulation models) with large databases, front-ended by a user-friendly interface, which is often graphical.

Figure 3.5 can be expanded to help highlight the important aspects for the production of DSSs (Figure 3.6).

- The database information
- The model base
- The decision maker dialog

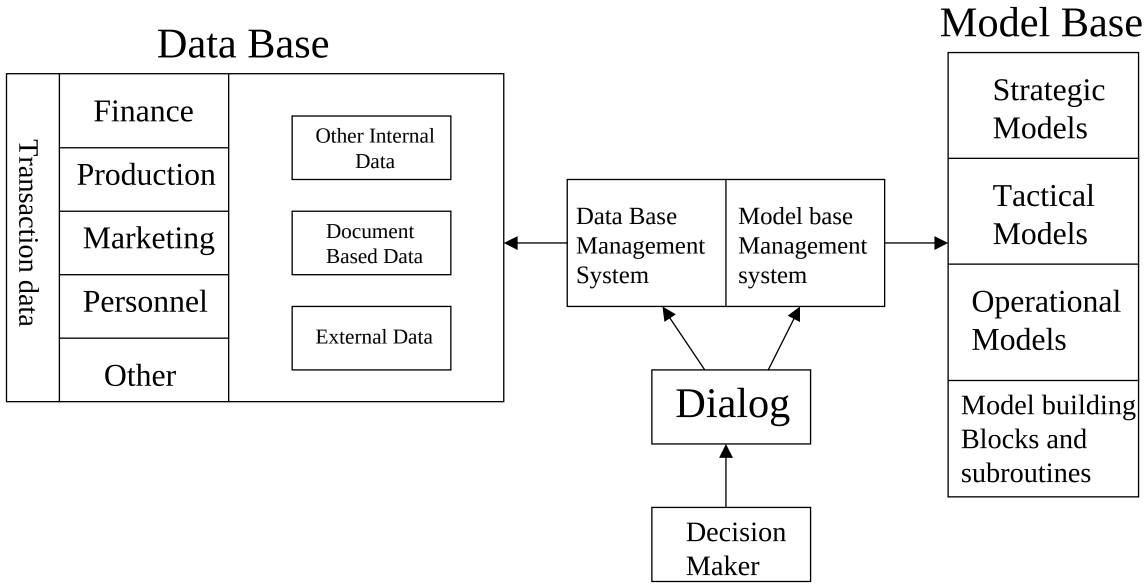


Figure 3.6: **Expansion of the DDM paradigm (Figure 4.1).** To give emphasis to the three important elements of DSS development (Sprague and Watson, 1996).

From Figure 3.6, various areas for consideration are highlighted with respect to DSS development. These shall be discussed with reference to the Tanzanian study. The various systems and products that have been developed during this research will be expressed and evaluated.

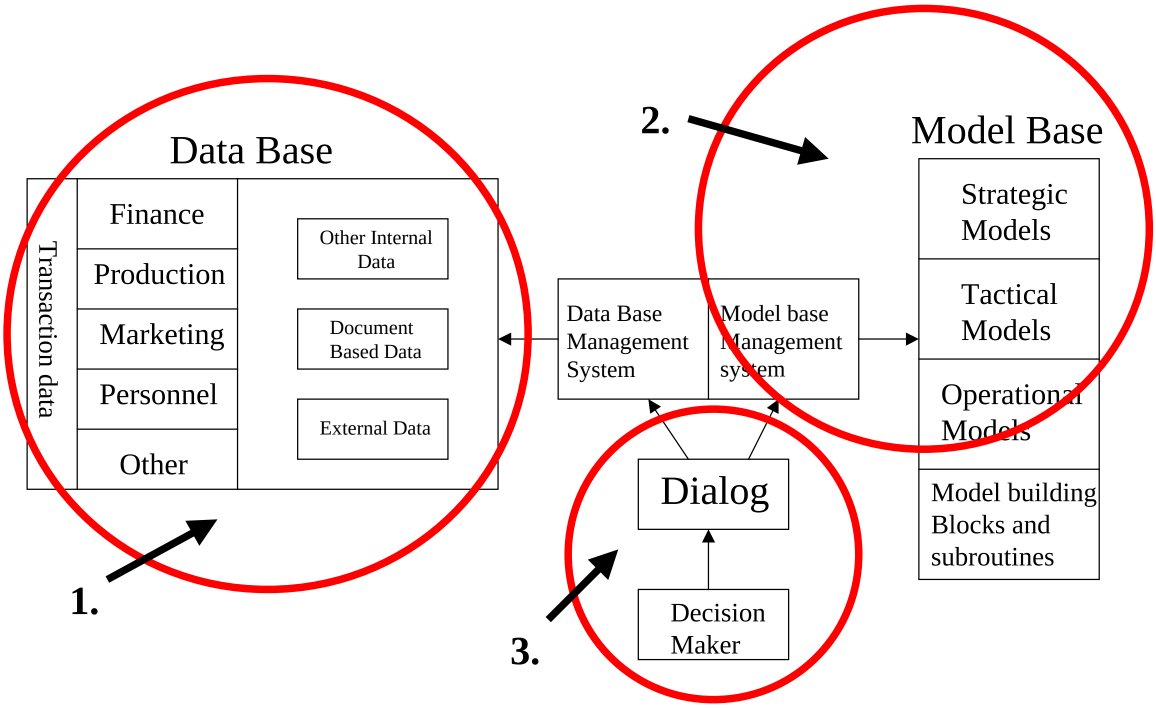


Figure 3.7: **<u>Areas of interest.</u>** The three main areas for DSS development have been highlighted; 1 = Data base, 2 = Model base, 3 = Dialog system.

3.8.1 Database Information

The first important aspect is that of database information, principally the collection of the information that will be utilised within the system being developed (Sprague, 1980). There are two data types – quantitative and qualitative – each of which has many sources as will be discussed in Chapter Four. Data can fall under four categories within databases (refer to Figure 3.8).

1. Internal
2. External
3. Document based data
4. Record based data

	Internal	External
Record Based	Traditional MIS	Public Data Bases
Document Based	Word Processing Records Management	Corporate Library

Figure 3.8: **Data categories.** The categories of data that can be collected for research projects and data gathering strategies (Sprague and Watson, 1996). (MIS = Management Information Systems)

Common data sources include finance, production, marketing and personnel. These sources are termed transaction data. Various methods can be used for collecting the required data, for example questionnaires (interaction with subject matter), experimental techniques, or through observation and recording. Once the data have been collected they need to be stored in a suitable way so that they can be extracted and used within the system being developed. In the case of the Tanzanian DSS the data is stored within a computer system such as Microsoft Excel or Microsoft Access, which can display the data in tabular form using spreadsheets. These forms/spreadsheets can easily be manipulated and utilised for further purposes. Databases can store both numerical and textual information, and various formatting can be applied to this information depending upon its ultimate use within the system being developed.

3.8.2 Model Base

The second important aspect is the model base. A model is a simplified description of some phenomenon, developed for a specific purpose. When describing models one inevitably thinks of quantitative models expressed in the language of mathematics intended for prediction. There is nothing in the above description requiring models to be numeric or predictive (Davis, 1974).

Environmental problems, such as the management of RWH in Tanzania, are characterised by a mixture of qualitative and quantitative information and environmental managers normally draw upon both scientific information (quantitative) and local knowledge (qualitative) in designing management strategies.

There are various types of models that can be applied for the development of DSSs. The common three are:

1. Strategic models
2. Tactical models
3. Operational models

The model used can be seen as the building blocks to something larger – a system with multiple capabilities. To utilise this function of a model, sub-routines need to be devised to help break the model into sub-component.

The modelling method that is used within the production of the Tanzanian DSS is simulation modelling that incorporates both strategic and operational models. This approach uses collected data to help develop mathematical relationships to represent specific processes, which can subsequently be used for predictive purposes. Sinclair and Seligman (1996) describe how this modelling approach helps to identify the most influential parameters of a system. Boote *et al* (1996) see models as providing a structure to a research programme, and being particularly valuable for synthesising research understanding and for integrating up from a reductionist research process. For the efficiency of research to be increased, the modelling process must become a truly integrated part of the research. Sinclair and Seligman (1996) make a similar point, seeing models as a way of setting our knowledge in an organised, logical dynamic framework, allowing identification of faulty assumptions and providing new insights.

For the purpose of the Tanzanian DSS, modelling principally involves the manipulation of numerical data to form relationships that can be used to simulate the "real" process, and have predictive capabilities. A structured approach should be applied when carrying out model development. The first aspect that needs to be considered is the question that is being investigated. The determination of potential inputs and the desired outputs from the model is fundamental. The required data and information then needs to be collected and subsequently analysed. This then leads into the decision-making process of how to present the model/relationships to the end user. The general approach is to utilise some form of programming application whereby a simple user interface can be designed and the complex relationships can be "hidden" from view of the user. On choosing the programming language to use, pseudocodes and sub-routines are written in the chosen language to represent the relationships. This is followed up by the development and design of the user-interface – the front end of the system. The final aspect is to complete the code writing for the production of the system.

MS Excel (Walkenbach, 2001) was used to store the data collected for the Tanzanian model. The decision had to be made as to which programming language to use for extrapolating the derived relationships. Particular focus had been given to the potential end users of the system to ensure that the developed DSS was not too complex to use and that it was functional. The primary end users were to be the extension officers in the two study regions.

When choosing which programming language or development application to use, various questions can be asked. These are as follows:

- Have the programs been used before?
- What is the knowledge base for the programs?
- Are they easy to use/learn or will training be required?
- What are the costs involved for using the application?
- Are there any time constraints surrounding the production of the model that might influence the language chosen?
- What existing programming languages are in use for the development of models?

As the desired outcome from the Tanzanian model was to be able to present management options for RWH, a programming language with the ability to show data sets graphically and in a clear way was required.

Two languages were chosen for consideration. These were Visual Basic (VB) (McBride, 1997; Deitel, 1999) and Delphi (Cantu, 1999; Teixeira, 1999; Lischner, 2000; Morris, 2000). By referring to the above questions, both of these languages were chosen as they have been used before and the development teams based in Nottingham and Tanzania have an understanding of the programs, hence there was a sound knowledge base.

Traditional programming is essentially linear and based on the flow of execution. Operations run for a fixed span or until they reach decision points written into the program, and interrupting these activities is often hard to do. Programmers are responsible for all aspects of their program, including the screen display and user interface, and must write code to do everything.

Programs are usually designed from the top down, perhaps following the Jackson Structured Programming method (Sprague *et al*, 1996), by deconstructing complex operations into successively simpler ones. Sometimes a modular approach will be taken, creating a program from a set of more-or-less self contained functions and procedures.

All this leads to the term 'event driven programming', which is the method of programming used by both VB and Delphi. Simply this means that before anything happens on the screen, an event has to take place, such as the pressing of a button or the movement of the mouse on a scroll bar. This method of programming enables sections (modules) of the program to be developed at a time that can later be put together to make the full program. It also helps to slow down the running of the program. This reduces the chances of the program crashing during the testing period as 'bite-size' sections are tested at a time before the full program is put together. If the modules are too large, the program is prone to crashing due to excessive computer memory usage.

Both Delphi and VB are ‘object-orientated’ programming languages. They revolve around ready-made objects, and they are ‘event-driven’, i.e. all the activities in a program are triggered by one event or another. Each object has its own properties, determining its position, size, colour, the appearance and nature of its text, and much more. Each object has its own event handling procedures. Neither Delphi nor VB require the programmer to write the code for these properties, they are automatically stored. VB and Delphi “know” what a button is for example. They can handle images, menus, dialog boxes, drive and directory lists.

In the Tanzanian DSS, the program code runs in response to events, and as at any point a whole range of events might be possible, the flow of execution is not fixed as in traditional programming. Operations can easily be interrupted and do not have to follow a particular sequence. This is advantageous for the users of the system as it enables them to carry out what they wish within the program when they want to – they are not bound by specific rules and guidelines.

The process of program design when using Delphi or VB reflects the nature of the system. It begins by creating the screen layout (user-interface) and works outwards from there, adding first the code that will run in response to specific events and then any necessary code to co-ordinate the whole program.

The choosing of an appropriate programming language for the development of the model within the DSS is a fundamental decision and will need to be noted on the final strategy for DSS development that is being expressed within this chapter.

To help decide which programming language to use for the development of the Tanzanian DSS, research into the two languages was needed.

Alongside the answering of the previously stated questions to help in choosing which language to use, seven additional points were considered. These were more functionality-focused and related to the programming languages capabilities. Table 3.2 details these further considerations.

Area or interest	Notes related to VB and Delphi
Accessibility	Both programs were accessible on the PC
Screen	The screen functionality is similar for both programs with the utilisation of property functions and easy navigation.
Text	Text can be handled in a variety of ways, both imported and freely entered.
Image handling	Images can be inputted within the forms and manipulated for various purposes. Images can also trigger events.
Data handling	Equations can be written and used within the programs that may be used for various management purposes. Data can be imported from external files and exported for further analysis.
Code writing	Both VB and Delphi use the same type of syntax for code writing
Running	Both programs can be run easily once the program has been written. If faults are found these are highlighted and the programmer can make the necessary amendments.

Table 3.2: **Programming language considerations.** These are the seven additional points that were considered when deciding whether to use VB or Delphi as the programming language.

From this research into the two potential programming languages to use, Delphi was chosen as the language for developing the Tanzanian DSS. The main reason for this choice was the language was well known to the developers of the DSS, this prevented the need for additional programming training etc. From Table 3.2, 'data handling' and 'code writing' were the two fundamental points closed off via the use of Delphi.

Alongside the numerical data that forms part of the model base, the data gathered from qualitative methods was incorporated within the model. Qualitative information for the Tanzanian DSS was captured through questionnaires and observations. The focus of this data was to determine farmers' perceptions to management options and to ascertain social status criteria and ranking scores. The majority of this information formed the basis of the management database.

From the extensive textual information collected it was necessary to determine what information was of greatest importance. This was in reference to classifying the criteria to be used for assessing perceptions of social status. As with quantitative data whereby applications such as Excel were used to analyse the data, different applications can be applied for analysing the qualitative information.

3.8.2.1 Model Base – social sciences and qualitative aspects

Language is the most common form of meaningful expression. Language not only incorporates the terminology and vocabulary with which we understand the world, and uses it to transform it, but it is also the medium by which we convey that meaning or interpretation to others. As well as being the tool we use to express our ideas and interpretations of the world, language contains the concepts and categories that describe and constitute the world in which we live (Hampson, 2000; Pease, 1997).

Most qualitative data is in the form of reports. These tend to be analysed by researchers reading and re-reading the information and drawing conclusions from its contents. Although computer packages can be used to help analyse this form of data, choosing the correct software package can be difficult.

Many qualitative researchers are deciding whether to use 'computer assisted qualitative data analysis software' (CAQDAS) (Kelle, 1995) and if so which package to use. The growing literature on CAQDAS expresses both hopes and fears (www.qsrinternational.com). The 'hopes' include the possibility to help automate, speed up and add structure to the analysis of the data. Of the 'fears', the predominant one is that CAQDAS will distance researchers from their data. To use CAQDAS one must read and ensure there is familiarity with the data. To ensure the validity of analysis it is best to keep returning to the original text.

The rising use of CAQDAS is resulting in the convergence towards a single orthodoxy of data analysis (Barry, 1995 and 1998). Researchers will be more likely to take what they can from the software and use supplementary non-computerised methods, than to confine themselves to the limitations of computer methods. CAQDAS tends to be applied only as another analysis tool for a project. As with the Tanzanian scenario it can be used in conjunction with the tools used for the development of the mathematical equations and relationships.

From research, three qualitative analysis packages became apparent as being useful.

- N6
- NVivo
- Atlas/ti

Each of these will now be discussed as a basis to which method to use. When deciding which software to use; if there is a clear preference for one type of analysis style or if the research project tends to be inherently more or less complex, this might help to clarify the choice (www.qsr.com).

NVivo

Unlike other qualitative packages, NVivo handles rich text records freely edited and coded. NVivo allows the user to create and edit documents internally or import them from an external source. NVivo takes qualitative inquiry beyond coding and retrieval. Unlike other packages, it was designed from the ground up to integrate coding with qualitative linking, shaping and modelling (Barry, 1995).

N6

N6 is the latest version of the NUD*IST software, the world's leading software for code-based qualitative analysis. It combines efficient management of non-numerical unstructured data with powerful processes of indexing, searching and theorising. N6 was designed for researchers who want to make sense of complex data. It offers a complete toolkit for rapid coding, thorough exploration and rigorous management and analysis. With a full command language for automating coding and searching, and a command assistant that formats the commands for the user, N6 powerfully supports a wide range of methods. Documents are imported singularly or in batches, in plain text with automatic formatting to the chosen unit of text. Coding on screen allows the researchers to monitor and manage the emergence of ideas. Coded material is displayed for reflection and revision. The visual displaying of information allows the researcher to test hypotheses, locate patterns or pursue a line of inquiry to obtain a confident conclusion.

Both N6 and NVivo run within a PC platform and if necessary the two tools can be linked. Both these systems share similar attributes.

Atlas/ti

The free form, loose structure of Atlas/ti may evoke anxiety in people and some may prefer the 'safer' more structured approach of N6. Conversely, those who are comfortable with a mass of data and with uncertainty may prefer the variety of options in Atlas/ti. It may facilitate seeing links between different aspects of the data and theoretical ideas. This qualitative analysis package is much more orientated towards aesthetics rather than ease of use. It is a powerful tool and has been applied to many projects – particularly those related to determining opinions related to medical issues (Hampson, Personal Communication, 2002).

As with choosing which programming language to use for model development, the same questions can be asked of CAQDAS.

This information into CAQDAS helps to determine which analysis technique to apply for the production of DSSs. In the case of the Tanzanian DSS, N6 or Nvivo would be the preferred option due to their data handling capacity and existing knowledge surrounding there application.

The two main aspects of the model base for the development of the Tanzanian DSS (and DSS development in general) have now been expressed, with reference to guidelines and analysis techniques.

3.8.2.2 Model Base – Geographical Information Systems

An additional modelling tool was applied that of geographical information systems (GIS) to generate geographical distributions to the DSS predictions. A GIS is an integrated software package specifically designed for use with geographical data that performs a comprehensive range of data handling tasks (Longley *et al*, 2001). These tasks include data input, storage, retrieval and output, in addition to a wide variety of descriptive and analytical processes. The design of any information system is greatly determined by the specific data and information needs of the user. Longley (2001) describes the potential advantages of GIS and concludes that GIS can provide fast, accurate, uniformity, and stable analytical and data storage methods. GIS technology provides ways to visualise, compare and analyse spatial relationships among large amounts of diverse data. Maps have made it possible to view and comprehend the physical, social and political distributions on the Earth. GIS provides a much more powerful window on attributes of today's environments.

The definitions of a GIS vary and the approach can be useful for different people. Table 3.3 below highlights some of these definitions and the groups of people who find them useful (adapted from Longley *et al*, 2001).

Definition	**Owner**
A container of maps in digital form	The general public
A computerised tool for solving geographic problems	Decision makers, community groups, planners
A spatial decision support system	Management scientists, operations research
A mechanised inventory of geographically distributed features and facilities	Utility managers, transportation officials, resource managers
A tool for revealing what is otherwise invisible in geographic information	Scientists, investigators
A tool for performing operations on geographic data that are too tedious or expensive or inaccurate if performed by hand	Resource managers, planners, cartographers

Table 3.3: Definitions of a GIS, and example of groups who find them useful

Table 3.3 clearly demonstrates how many problems could be solved or looked into using GIS tools. But, if so many problems can be seen as geographic, how does one distinguish them from each other? Longley *et al* (2001) gives three responses to this question:

1. There is a question of scale, or geographic detail
2. They are distinguished on the basis of intent or purpose
3. Some problems can be distinguished on the basis of their time scale

With this in mind it is important to have a good understanding of why one is applying GIS to the system/model they are producing. With regard to the Tanzanian study the concern was with decision making on a management level for resource capture and utilisation.

GIS techniques were applied by the team in Tanzania for the development of maps that present the agricultural conditions within the catchment areas, alongside displaying the local infrastructure and topographical details (Ludovic, 2003). These maps were developed using the computer software 'ArcView'. This software allows for easy storage and uploading of data from external sources and converting this, using pre-defined map (area) templates, into the desired maps - Figure 3.9.

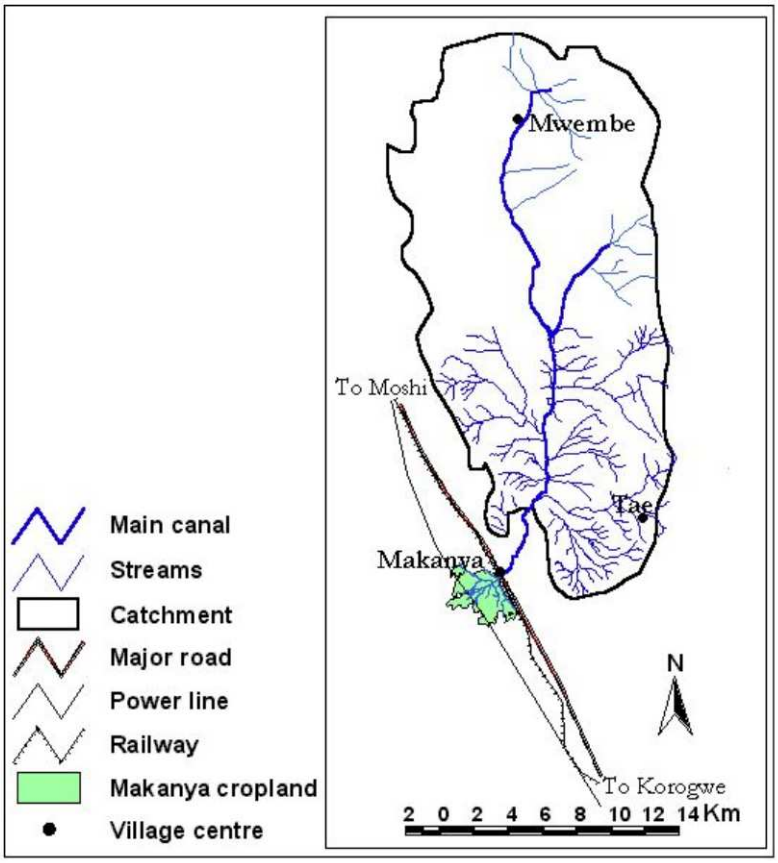


Figure 3.9**: <u>WPLL location map.</u>** A map showing the location of Makanya, Mwembe, and Tae villages.

For the development of the GIS there are four technical parts that are required.

1. Network
2. Hardware
3. Software
4. Database

The architecture of the GIS follows a simple flow of execution as detailed in Figure 3.10 below. Principally they are designed using computer aided design (CAD) systems.

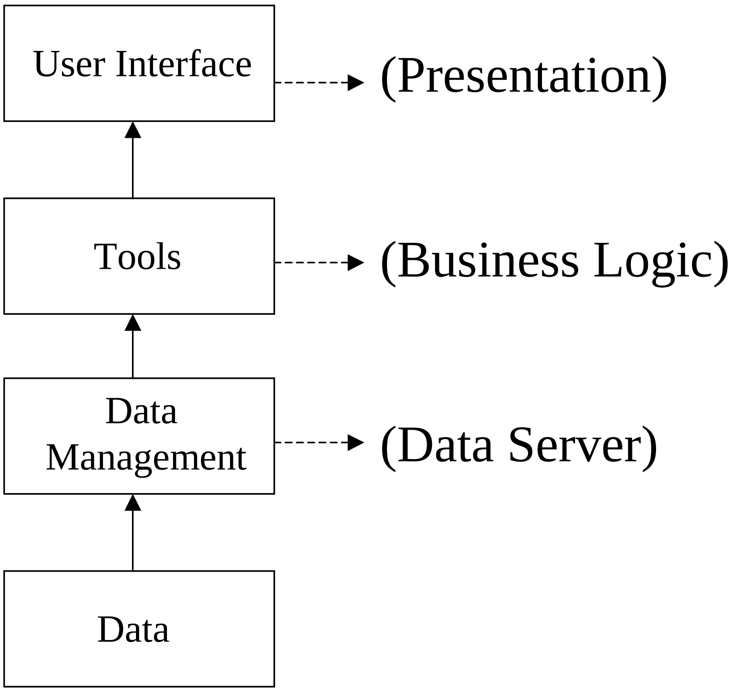


Figure 3.10: Architecture of a GIS

By following this simple flow chart the maps as demonstrated by Figure 3.9 have been produced for the benefit of understanding the geographical situation (constraints and resources) in Tanzania.

3.8.3 Dialog management system

The two main aspects that make up the DDM paradigm have been described. The final aspect that needs to be considered when setting up an approach for the development of DSSs is to have an understanding of the decision maker and the dialog management system.

An appreciation of the importance of the dialog component is gained by recognising that from the users perspective, the dialog is the system (Sprague, 1996). What the user has to ‘know in order to use the system’, the options for ‘directing the systems actions’, and the alternative ‘presentations of the systems responses’ are important. Bennett (1977 and 1983) refers to these dialog components as the ‘knowledge base’, the ‘action language’, and the ‘presentation language’, respectively. Unless they affect the dialog, the user typically has little interest in such considerations as hardware and software used, how data are stored in memory, and the algorithms employed by the models. Such factors are often transparent to the user; that is they are neither seen nor recognised. However these elements do need to be documented alongside the development of a strategy for DSS development.

When designing the DSS dialog it is important to recognise who the potential users are – the decision makers. In some instances there is a single user; more typically, the DSS will have multiple users (Hogue, 1983 and 1987).

It should be recognised that a dialog involves simplicity versus flexibility trade-offs (Sprague, 1996). Dialogs that are simple to use typically offer less flexibility. For example, the old question-answer approach requires the user to respond to questions (Sprague, 1980). While this approach is simple and is often appropriate for novice users performing well-structured tasks, it does not provide flexibility beyond what was planned by the system's designers. In this situation the system is largely in control (Sprague *et al*, 1980 and 1982). Menu-orientated systems impose the same kind of structure on the user even though they provide a different dialog approach. By way of contrast, command languages place the user more in control but require additional knowledge to use the system. Command languages normally employ a verb-noun syntax (e.g. run simulation, print report).

When a DSS supports several uses (as with the Tanzanian system that gives management options for both nutrients and water), multiple dialog options can be designed for the system. This is sometimes referred to as a tiered dialog approach because there are several layers of dialog option (Sprague, 1996). The availability of multiple dialog options also supports differences in cognitive style among users. For example, a 'systematic' person processes data in a structured, step-by-step process, whereas an 'intuitive' person may jump from one analysis process to another. A systematic person may feel comfortable with a menu-orientated dialog, but an intuitive person may want the flexibility offered by a command language.

With regard to the Tanzanian DSS a more systematic and hence menu-orientated approach was adopted as this gave structure to the system to allow for simple results to be extrapolated.

Within this final aspect of DSS development, consideration has to be given over to the design of the user-interface hence the choice of system that will be used to “house” all the developed relationships, models and data storage facilities. Principally the decision that has to be made is ‘what programming language to use?’ This area has been covered while discussing the model base structure. Generally object-orientated languages will be utilised if the proposed DSS is to be extrapolated to a variety of users. These languages allow for simple systems to be developed that have the ability of hiding from view the complexities of the relationships involved as the users of the system are unlikely to be concerned with these. As already mentioned, two options were available, Delphi or VB. Recent developments into the development of computer systems has seen an increase in the use of Web based tools/applications such as MySQL and FLASH (Vogeleer, 2005; Reinhardt *et al.*, 2006). However, for the Tanzanian DSS, Delphi was applied.

Many factors have to be considered when designing the user-interface of a program. These include the layout/structure of the information being portrayed, the colours being used, text formatting, general aesthetics and the actual flow of the system.

These factors should also be discussed with the potential end users of the system to help enhance the uptake and extrapolation of any proposed DSS.

3.9 Strategy Development

The three underlying components that make up the structure of a DSS have been outlined:

- Data base
- Model base
- Dialog function

Each has been expressed with reference to the development of the Tanzanian DSS, detailing guidelines and analysis of the systems used for development. The next stage is to link this information (guidelines and systems analysis) with the systems development processes outlined earlier in this chapter – such as the Simon’s model

(Marakas, 2000). This will give rise to a single coherent approach for the development of DSSs, particularly those interested in extrapolating management options.

It must be noted that this is only one possible strategy that could be applied. It is open for amendments and ultimately it is the DSS developer who has the right to choose an approach.

The method outlined below highlights all the various considerations that should be adhered to and adds structure to the flow of decision-making and DSS development.

3.9.1 Developed Strategy

Figure 3.11 illustrates the steps that were applied for the production of the Tanzanian DSS and can also be used as a generic approach for the development of DSSs that incorporate various types of data.

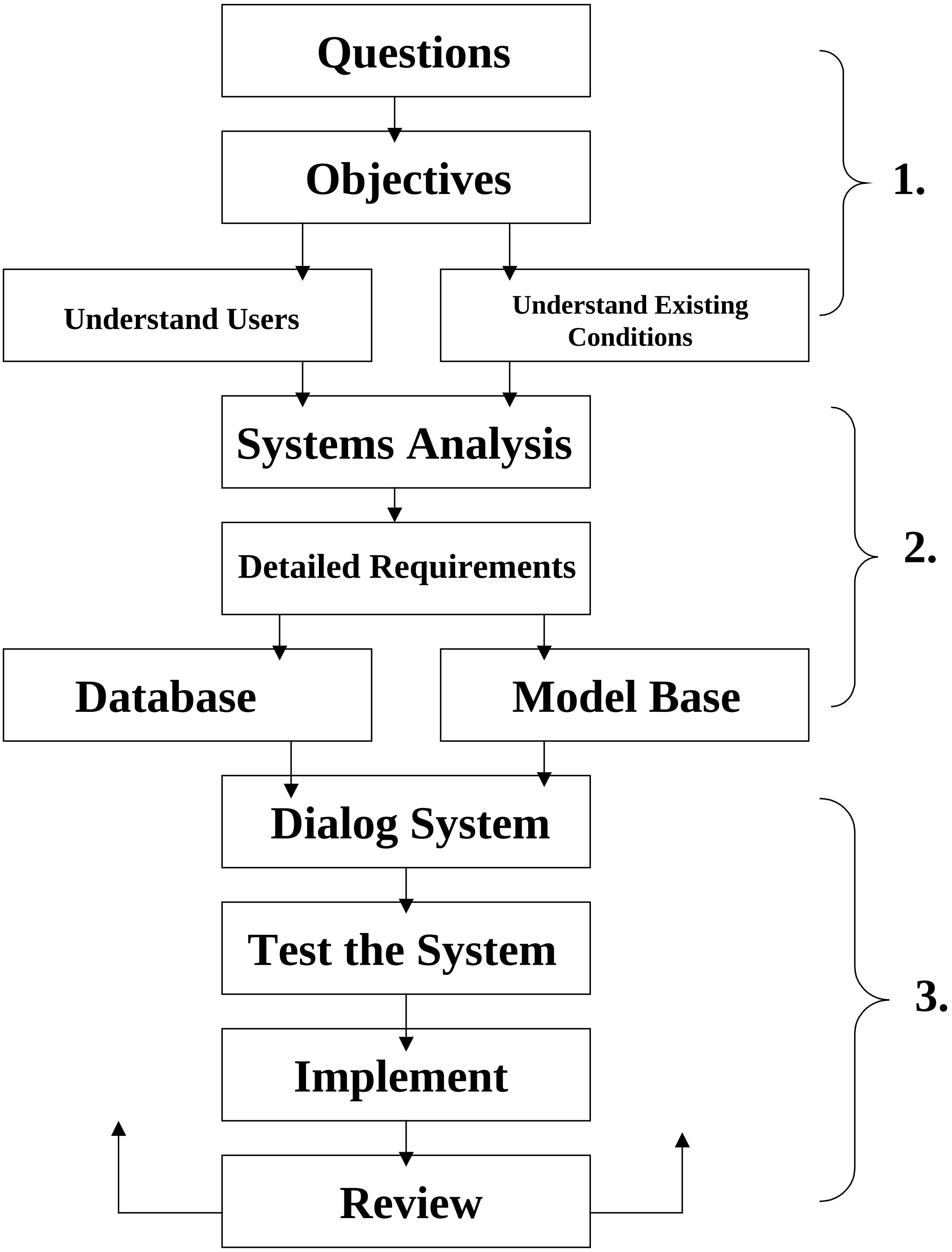


Figure 3.11: **Tanzanian DSS strategy.** The strategy development of the Tanzanian Decision Support System. Section 1 = Descriptive Phase, Section 2 = Explorative Phase and Section 3 = Planning Phase.

This framework expresses the important aspects that should be considered during the production of any DSS. The approach is split into three phases as described by

Stroosnijder (2001), and within each phase (Table 3.4) both qualitative and quantitative information is considered.

Phase No.	Title	Comments
1	Descriptive Phase	Within this phase the developer and researcher determine the objectives of the study and outline questions that the DSS should answer. An understanding of the potential users and existing conditions is also determined. This is achieved through initial observations of the study region and documenting any findings.
2	Explorative Phase	This phase entails the evaluation of existing conditions and subsequently the development of new systems to help tackle the proposed objectives. Detailed requirements specifications should be drawn up listing all study areas, potential limitations, required data fields and the development processes/lifecycle for developing the DSS. Data will be collected that forms both the database and the model base that make up the substantial components of the DSS. Systems analysis and systems development takes place in this phase.
3	Planning Phase	Within this final phase the system or processing tool that is to house the DSS is chosen and the already derived model and database are incorporated within this end system – the dialog system. Testing and risk assessments are carried out on the DSS. User acceptance testing (UAT) is fundamental and a log of any issues should be recorded, a template for this log is expressed below (Table 3.5). The DSS then needs to be implemented and tested in its natural environment. Continual reviews (6 monthly basis) should be carried out to ensure the usability of the system and to make improvements etc.

Table 3.4: Phases of system development

Table 3.5 highlights the fields that need to be recorded within an issues log. The issues log is instigated within the Planning Phase for DSS development to help record any issues that arise during the development process.

No.	Date	Author	Issue	Status	Priority	Comments	End Date	Responsibility

Table 3.5: Template for the issues log for recording any discrepancies observed when testing the DSS.

This is a generic approach for DSS development yet it shows how a social sciences approach to modelling (Stroosnijder, 2001) can be applied within what is commonly thought to be the domain of mathematicians. Each step in the process requires the developer to be aware of both the physical (numerical) and social (language/perceptions) factors that may be of relevance to the final outcome.

This can be demonstrated by applying Figure 3.11 and Figure 3.12 to the Tanzanian study. Particular interest lies in the understanding of the objectives, development of the database and model base, the application of CPR management and the review procedures.

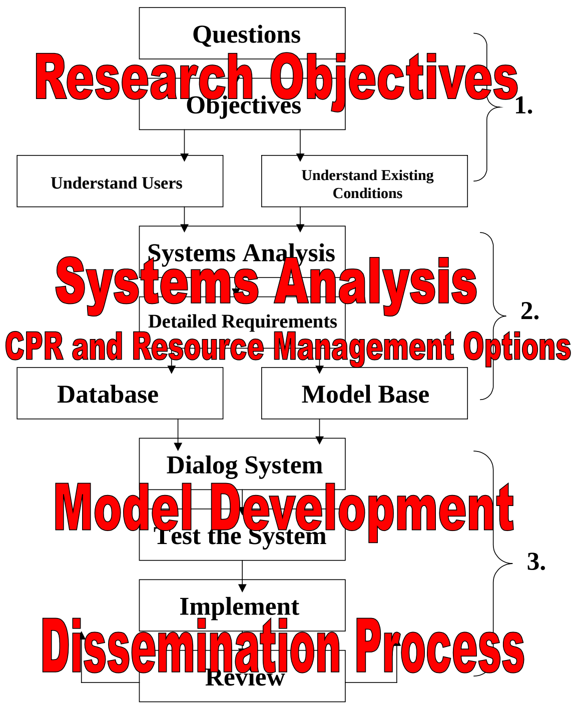


Figure 3.12**: <u>DSS Processes,</u>** highlighting the main processes that were applied during the development of the Tanzanian DSS.

3.10 Application of the strategy to the Tanzanian study

With regard to the Tanzanian study, the descriptive phase was relatively straightforward to comprehend. The objective of the DSS was clearly stated at the onset of the research – to produce a DSS to aid in the management of RWH and natural resources. Another objective was to utilise both the potential qualitative and quantitative data for the production of the DSS. Questions were asked by all parties involved in the research to help ascertain the focus of the DSS being produced. These questions were essential as they helped to give direction and structure to the approaches to be used for the production of the Tanzanian DSS.

Of the questions asked, two form the next steps in the process of DSS development being expressed here; 1) understanding the users of the potential system and 2) understanding of the existing conditions in the study regions.

The term "user" is a loose one and requires further verification. There were various levels of users involved in the Tanzanian DSS. The levels involved were (re-iterated from chapter two):

- **Development user team –** these were the people who were involved in collecting the data for the development of the system and those who actually carried out the programming and system development and execution.
- **End users –** these were the extension officers and scientific researchers in the study regions who would work with the beneficiaries of the system to utilise the functions within the system.
- **Test subjects –** these were the farmers in the study regions for whom the system was being developed.
- **Beneficiaries –** these were the farmers of different social status within the study regions who would ultimately benefit from the system being developed.

The existing conditions relating to water and nutrient management were obtained via qualitative research techniques including questionnaires, and through observation. This information was collated and through analysis it was possible to determine the areas of management that required particular focus for the development of the solution – areas within the explorative phase.

Systems analysis is the first element to consider, and it features both in the explorative phase and the planning phase. The systems analysis involved in the explorative phase is with reference to the existing management approaches. Whereas in the descriptive phase methods were documented, in this phase methods were explored to draw conclusions surrounding their feasibility. All the information was documented for future reference.

Analysis was carried out to help the development team to understand what agricultural practices and management techniques were already present in the study regions, and to gauge the farmers' perceptions towards these methods. Possible alternative management options were expressed alongside the proposed DSS to be developed, to the potential beneficiaries of the research. It is advisable when developing new management strategies, particularly through the use of computers, to maintain communication channels between the developers, end users and the beneficiaries. This communication string should help in the future uptake and extrapolation of any new management strategy as all users will have been involved in the development.

Following on from the systems analysis, the developer of the DSS should have a good understanding of the requirements needed for the various components that are to be tackled by the DSS. These requirements can be split into the two fundamental components of a DSS as detailed by Sprague and Watson (1996) – the database and the model base. The principal function of these two areas is the collection of data sets, subsequently followed by the manipulation of this data to form the model and underlying core or 'brain' of the DSS – the epicentre. The contents and processes for the development of the database and model base have been discussed within this chapter. With regard to the Tanzanian DSS, simple mathematical relationships were derived for predicting the affects of water or nutrient applications on the growth of maize and rice.

Further detailed requirements needed to be outlined to ensure that sufficient data was collected for the development of the model to be used within the DSS. This information was tabulated and referred to during data collection. The information centred on resource capture qualities and factors that would influence these processes. Presenting this information in a detailed list helps to give focus to the information that is being collected by the researcher and helps to ensure that the correct information is collected. Both numerical and observational requirements were stated. For example, the numerical volume of rainfall being received in a catchment was required for understanding the potential level of water that could be applied for agriculture. The observational understanding obtained through discussions of how the farmers partition the levels of water they receive was also stated.

Once the data types and formats were derived, the actual model base and database to be used for the DSS were developed. Firstly decisions had to be made surrounding the tools to be used for the development of these two fundamental elements of DSSs. For the Tanzanian DSS the tools applied were Microsoft Excel, Microsoft Access, Delphi, N6 and ArcView.

It is essential that these chosen systems will link with the ‘dialog system’, which is the next consideration that was made. Questions were asked as to how the DSS was going to be presented to the end users. Principally this is the decision of what programming language or presentation tool was to be used for housing the research and models that had been developed. The chosen approach for the Tanzanian DSS had to be able to handle mathematical models and the ability to input user criteria related to socio-economic factors, for deriving management options. The management options need to be able to be extrapolated in a useable format as well. All the aspects within the research needed to be considered during the development of the final DSS user interface system, the numerical relationships for deriving the effects of water and nutrient application on the growth of maize, and the CPR management criteria that might influence the decision-making processes of the farmers in the study regions as to whether they will apply a particular outcome from the system.

The functionality of the system also needed to be pitched at the correct user level. The potential users of the system were to be the extension officers in the study regions. These individuals already possessed knowledge behind the production of the DSS and its purpose which enabled the production of the tool to be pitched at a relatively high level of understanding. It was not necessary to dumb down the tool too much (Kajiru, Personal Communication, 2002).

Once the system was completed it was necessary to test it and actually obtain some figures from the model. These figures could be compared to actual physical data obtained from the study regions to ensure the outputs obtained are feasible. This introduced the concept of a feasibility analysis. The Tanzanian DSS was extrapolated to the team in Tanzania where it was implemented. During the implementation of the system, observations were made surrounding the uptake and understanding of the system.

The final element that needs to be considered is the need to continually review the developed system and make amendments and updates if necessary. Computer systems can become obsolete in a relatively short period of time, and hence a review of any DSS tool should be scheduled for every six months to allow for updates to be made (Matthews and Stephens, 2002).

The three DSS development phases were applied to the Tanzanian scenario as detailed below.

Phase One:

The objectives of the Tanzanian DSS were to help give structure to the management of RWH. The production of a DSS that incorporated both quantitative and qualitative data was deemed a feasible solution. The questions that were asked were related to gaining an understanding of the study regions and recording the existing agricultural practices that were in place. Alongside this, an understanding of the potential users of the system was required. The farmers in the study regions were classified through research into their social status and were classified as rich, medium or poor. The Tanzanian DSS aimed to focus upon the poorer members of the community and to aid in poverty alleviation. As well as understanding the potential users of the DSS, research was also carried out to determine if any previous computer based systems were in place. In the case of Tanzania, there was knowledge surrounding the use of the PT model. Knowledge of this sort would ultimately help in the dissemination and uptake of any new system, as the use of computer systems would not be a complete surprise to the end users.

Phase Two:

Within the second phase the analysis of any existing systems was carried out to determine if any features of these systems could be incorporated within the new system. More importantly, the data requirements for the development of the Tanzanian DSS were specified. Lists were produced to detail the data parameters that were required for building the mathematical relationships that were used within the model base of the system. Additional data were collected based upon existing conditions and perceptions towards management options, these data sets were collated within simple relational databases that could be accessed for determining existing agricultural practices for example (RWH techniques, crops grown). With the collection of the various requirements the actual development of the system took place within this phase. Within the development of the Tanzanian DSS and the explorative phase, common pool resource considerations were introduced. The principle focus was upon the factors that influenced the allocation of the resources – water and nutrients – within the community, as well as the factors that affected and contributed to the social status of community members.

Phase Three:

Within the planning phase the programming language, Delphi, was chosen for building the Tanzanian DSS. The previously derived relationships and database systems from the explorative phase were uploaded and incorporated within Delphi. This language acted as the dialog system – the one that would help the model base and database 'speak' to one another.

3.10.1 DSS extrapolation and uptake

During the development of the Tanzanian DSS it was necessary to be aware of how the system would be instigated within the study regions and who would be the end users. With this in mind, research had to be carried out to help understand why some agricultural DSSs are poorly adopted, and to find ways to ensure that the Tanzanian DSS would be adopted and utilised.

The understanding of scepticism towards computerised management tools is fundamental. The following table (3.6), adapted from Matthews and Stephens (2002) illustrates the reasons why models and DSSs are often dismissed as management tools.

Reasons for poor adoption of Decision Support Systems
• Unclear definition of clients/end users • No end-user input prior to or during the development of DSS • DSS does not solve the problems that the client is experiencing • DSS does not match their decision making style • Producers do not trust the output due to lack of understanding of the underlying theories of the models utilised • Producers see no reason to change current management practices • DSS does not provide benefit over current decision making system • Limited computer ownership amongst producers • Lack of field testing • Cannot access the necessary data inputs • Lack of technical support • Lack of training

Table 3.6: Reasons for poor adoption of Decision Support Systems (Matthews and Stephens, 2002)

These points need to be overcome to help ensure the DSS that is produced is successful. Matthews (2002) details seven requirements for the production of successful DSS packages. These are outlined below in Table 3.7.

Requirements for successful DSS packages
1. Address real problems (often complex) not readily solved by rule of thumb (e.g. pest management and irrigation scheduling require decision making on issues that vary from one season to the next. The cost of making a mistake is high and therefore use of DSS may be worthwhile). 2. Address problems that will be costly if the decision is not made correctly. 3. Must be easy to use and output easily understood. 4. Must be targeted at the client. 5. Must not require an experienced computer programmer to operate, or must be part of a system where the operator works as a consultant passing on the relevant outputs in a useable manner. 6. Must be introduced to the client with a thorough training package and continued support. 7. Need to be maintained and updated with changing technology and in response to user demand.

Table 3.7: Requirements for successful Decision Support Systems (Matthews, 2002)

The fundamental parts of developing any computer system are:

1. Have clear objectives from the onset
2. A suitable communication strategy between system developers and the end users
3. A close affinity with the end users to ensure the system that is being developed answers the proposed problem

The DSS was completed and subsequently disseminated to the team in Tanzania where the extension officers have had access to its capabilities and processing. On attaining feedback on the system, further developments and enhancements can be made. Reviews and checks on the system should be carried out also. It was also important to specify to the end users that the Tanzanian DSS only extrapolates potential management options. There is still an element of risk with the application of the specified allocation of resource that is obtained from the DSS, as with any biological system, it is difficult to fully predict its functionality and lifecycle.

3.11 Summary

A sound framework and approach for tackling the development of DSSs is of utmost importance for ensuring a feasible solution to a stipulated objective is achieved. Various development strategies are present in the literature (Marakas, 2000). This research has taken on board the various strategies outlined in this chapter and has shown how these can be combined to form a single strategy for the development of DSSs as outlined in Figure 3.11. The importance of this combining of strategies helps to give focus to the development of future management systems. Less time will be spent sifting through the numerous available strategies for DSS development, as it is possible to combine the various approaches to form a single strategy.

Anon (1988) sums up the decision stages – see Figure 3.2. This can be further re-iterated by the seven phases of system development as detailed by Taylor (2001), see Table 3.8 below.

The Phases of Decision Support System Development
1. Definition Phase: Precisely define the problem to be solved, its magnitude and who will work on it
2. Requirements Phase: Develop a detailed description of exactly what the development effort will produce. Gather all the relevant information and put it into a requirements document and get client agreement.
3. Evaluation Phase: Determine exactly how you will meet the requirement. What tools will you use? How will you deploy your development team? Determine time and budget constraints.
4. Design Phase: Create a database model and the design a database and database application that satisfy the terms of the requirements document.
5. Implementation Phase: Build the application and maintain documentation of all processes during development.
6. Final Documentation and Testing Phase: Test the database and application thoroughly, trying out every conceivable input and condition. Primarily try and 'break' the system. Determine where the system falls over and document and review the issues.
7. Maintenance Phase: Fix any bugs that arose during testing. Provide updates and enhancements to the system on a rotational basis.

Table 3.8: The seven phases of decision support system development (Taylor, 2001)

There are various key points that should be observed in relation to this general approach. In the context of this project, the important aspects were related to design, analysis, feasibility and implementation. The following tables illustrate some of the questions that needed considering during the production of the Tanzanian DSS. These are general questions that can be used for many project scenarios.

Table 3.9 considers ***feasibility*** aspects of the project initiation.

Task	**Pointers**
Determine scope and objectives	-What is the scope of the project? -Who will be involved in the project? -Produce a detailed plan for the approach to the project.
Examine existing systems	-Gather information from reliable sources with respect to the project in hand. -What are the functions of the project? -Is any data involved and what are the frequencies and volumes. -Evaluate the existing system.
Determine requirements	-Analyse the objectives -Are there any security or legal considerations to be made? -What are the areas of the system that have the greatest opportunity for improvement?
Evaluate solutions	-Consideration of the computer solution -What packages or equipment are going to be used? -Design alternatives -Possible impacts on other systems
Prepare development plan	-Devise an approach -Outline an implementation plan

Table 3.9: Feasibility questions and considerations when approaching a project. Adapted from the Systems Development Cycle (Anon, 1988b)

Table 3.10 considers aspects of ***analysis*** in relation to existing products and future products.

Task	**Pointers**
Scope and objectives	-Define the requirement of the project in detail and identify issues and how they will be handled. -Who will be involved?
Analyse existing systems	-Gathering information about existing systems and determining their performance and identifying improvements.
Determine detailed requirements	-Analyse performance, functions and information requirements. -Determine contingency requirements
-Develop outline new system	-Enhancement of systems using acquired information -Outline functions – inputs and outputs -Select what equipment is to be used for the production of the package. -Consideration of approach

Table 3.10: Analysis considerations for the production of computer systems. Adapted from The Systems Development Cycle (Anon, 1988b)

Table 3.11 illustrates some of the issues related to the design approach, in the context of this sort of project.

Task	**Pointers**
Produce logical system design	-Cross-referencing between processes outlined in the analysis with those used within the design. -Ensure progression of the development of the design
Produce provisional designs	-Form initial designs -Test these against design criteria and check structure requirements. -Performance estimation and refinement of design
Design systems	-Physical constraints and design objectives -Considerations should be made into which systems and approaches should be used – for example what programming languages to implement.
Complete detailed design	-Record the initial and final designs -Add justifications to the designs
Outline system test plan	-With the final design it is necessary to test it and make amendments. -Following testing it is possible to upgrade and improve the design.

Table 3.11: Design considerations related to the approach used to produce computer systems. Adapted from The Systems Development Cycle (Anon, 1988b)

Table 3.12 gives rise to implementation considerations – this is an aspect that had to be considered with respect to the production of the DSS.

Task	Pointers
Set up production environment	-Installation of hardware, software and network. -Creation of software environment -Conversion of package development -Conversion of data
Acceptance testing	-Testing of the system -Ensure those using the system understand its capabilities. -Test the running of the program -Make relevant changes
Changeover	-Transfer of system -Acceptance of the final product by the end-user. -Production of implementation report

Table 3.12: Implementation consideration for the uptake of newly developed computer systems. Adapted from The Systems Development Cycle (Anon, 1988b)

By having an awareness of these various considerations and factors that might influence the development of DSSs, it is possible to add focus to the DSS that is actually being developed. However it is ultimately the individual developers decision as to what approaches to apply for the development of the system that they are producing.

From the onset of the development of the Tanzanian DSS various frameworks for DSS production were available. It was possible to take the important elements of these frameworks to help develop the singular approach as expressed in this chapter.

<u>Chapter Four</u>

QUANTITATIVE AND QUALITATIVE RESEARCH

This chapter gives details surrounding the types of data that can be collected for the development of the Tanzanian DSS and outline any issues surrounding its collection. The chapter is split into two sections. The first focuses on detailing the literature surrounding quantitative and qualitative research. The second section takes this information and applies it in the context of the Tanzanian DSS, culminating in the illustration of some of the data that have been utilised within the development of the Tanzanian DSS.

4.0 Introduction

Scientists are often faced with the difficult decision as to which research and data collection/analysis techniques to apply to their specific problem. Quantitative or qualitative methods can be applied by themselves or a combination of the two methods can be applied (Creswell, 1998 and 2003).

The strategies applied depend on the research being undertaken and the potential outcomes from the research (Bryman, 2004; Silverman, 2004). The Tanzanian DSS for RWH management requires both types of data. Numerical (quantitative) data is required for relationship building, as are individual's perceptions (qualitative) towards techniques, for the development of the management tool (Hatibu, 2002). The Tanzanian management DSS also combines the two data collection methods.

4.1 Quantitative, qualitative and multi-strategy research methods

4.1.1 Quantitative research

Quantitative research begins with the collection of statistics, based on 'real' data (e.g. yield values), observations or questionnaires (Bryman and Cramer, 2001). Problems that are to be addressed by quantitative reasoning illustrate a greater understanding of what factors or variables influence an outcome (Bryman and Burgess, 1999).

Quantitative research may be from an impersonal point of view and the past tense may be used to provide ‘objectivity’ to the language of research (Bryman, 2004). Quantitative research is much more focused on the acquisition of numerical data sets that can subsequently be manipulated and analysed to provide statistical predictions, relationships and conclusions. Statistics can easily be distorted, as indicated by Disraeli’s quote “*there are lies, damn lies, and statistics*”. Therefore an awareness of quantitative data analysis greatly enhances the ability to recognise faulty conclusions or potentially biased manipulations of the data/information (Bryman, 1988 and 2004).

When working with quantitative data or carrying out quantitative research, it is very important to have an understanding of the potential analysis techniques that may be applied following data collection. The following statement as quoted from Bryman (2004) is a common assumption made by quantitative researchers:

“I don’t have to concern myself with how I’m going to analyse my survey data until after I’ve collected my data. I’ll leave thinking about it until then, because it doesn’t impinge on how I collect my data”.

The quote above is a common error that arises because quantitative data analysis looks like a distinct phase that occurs after the data have been collected.

However, quantitative data analysis is seen as a technique that occurs typically at a late stage in the overall analysis process (Bryman, 2004). It is also a distinct stage however thought should be given to its application throughout the research process to ensure the feasibility of its application and outcomes.

When analysing quantitative data one should be fully aware of what techniques one will apply at a fairly early stage – for example, when one is designing a questionnaire or observation schedule. Two main reasons for this are:

1. One cannot just apply any technique to any variable. Techniques have to be appropriately matched to the types of variables that have been created through the research. Hence one needs to be fully aware of the classification of variables.

2. The size and nature of the sample are likely to impose limitations on the kinds of techniques that can be applied.

Therefore, one needs to be aware that decisions made at quite an early stage of the research process will have implications for the sorts of analysis performed and potential outcomes from the research.

The types of information that the researcher will receive from the questions or decisions they make, varies depending on the type of question. Bryman (2004) states that the outcomes from quantitative research can vary in scope. He goes on to say that some questions give rise to 'real numbers', others are often in the form of 'dichotomies' (either/or answers), and some utilise lists and categories with ranking procedures. These considerations for the type of quantitative data that can be collected leads to a classification of different types of variables that are generated during research (Bryman, 2004; Silverman, 2004). As already mentioned (point 1 above) it is important to have an understanding of the type of variables you are working with as this will influence the potential analysis that can be performed on the data.

The four main variable types are:

- Interval/ratio variables
- Ordinal variables
- Nominal Variables
- Dichotomous variables

Table 4.1 gives a brief description of the variable types.

Type	Description
Interval/Ratio	Variables where the distances between the categories are identical across the range
Ordinal	Variables whose categories can be rank ordered but the distances between the categories are not equal across the range
Nominal	Variables whose categories cannot be rank ordered; also known as *categorical*
Dichotomous	Variables containing data that have only two categories

Table 4.1: Different quantitative variables and their descriptions. (Adapted from Bryman, 2004).

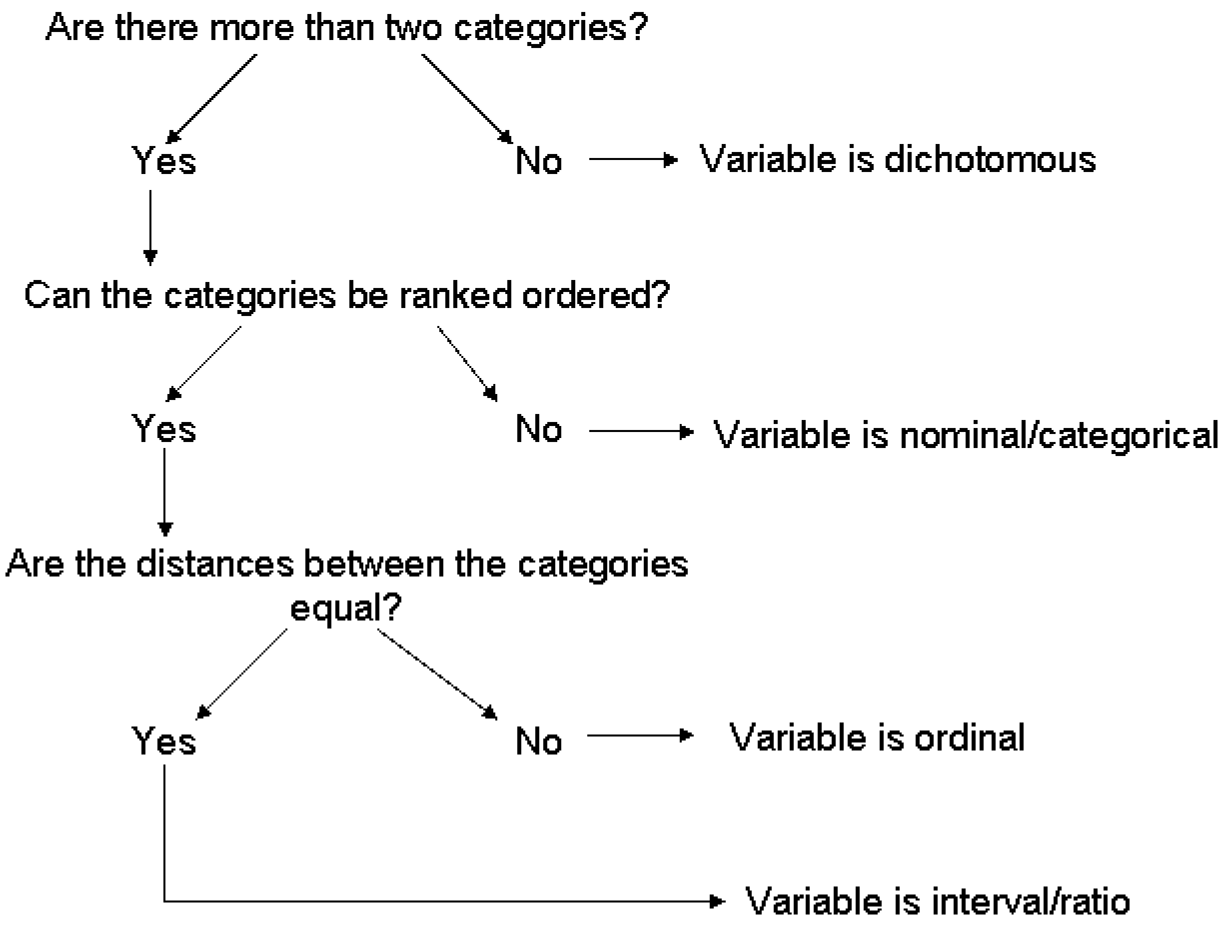


Figure 4.1: The flow of execution for deciding what type of variable one is working with. (Bryman, 2004)

Figure 4.1 above illustrates the flow of execution for deciding what type of variable the researcher is working with.

Analysis of quantitative data is dependent on the type of variables being researched. Three types of analysis can be performed.

The first is ‘Univariate’ analysis, which refers to the analysis of one variable at a time. Common methods used of univariate analysis include the development of frequency tables and the generation of representative diagrams (Bryman, 1998 and 2004). The second approach is ‘Bivariate’ analysis, which is concerned with the analysis of two variables at a time in order to uncover whether the two variables are related. Exploring relationships between variables means searching for evidence that variation in one variable coincides with variation in another variable. Many methods can be applied, however this depends on the nature of the variables being investigated. Methods include the application of contingency tables and statistical analysis/manipulation. The third approach is ‘Multivariate’ analysis, which entails the simultaneous analysis of three or more variables (Cramer, 1998). For this approach, three aspects have to be considered: (1) Could the relationship be spurious? (2) Could there be an intervening variable? (3) Could a third variable moderate the relationship?

The majority of quantitative information/data is collected via the use of questionnaires, surveys or by carrying out experimental designs.

A survey design provides a quantitative or numeric description of trends, attitudes or opinions of a population by studying a sample of that population (Creswell, 2003 and 2005). From sample results, the researcher generalises or makes claims about the population. It is necessary to express the details surrounding the population as these may influence the information being obtained.

4.1.1.1 Quantitative Research Process

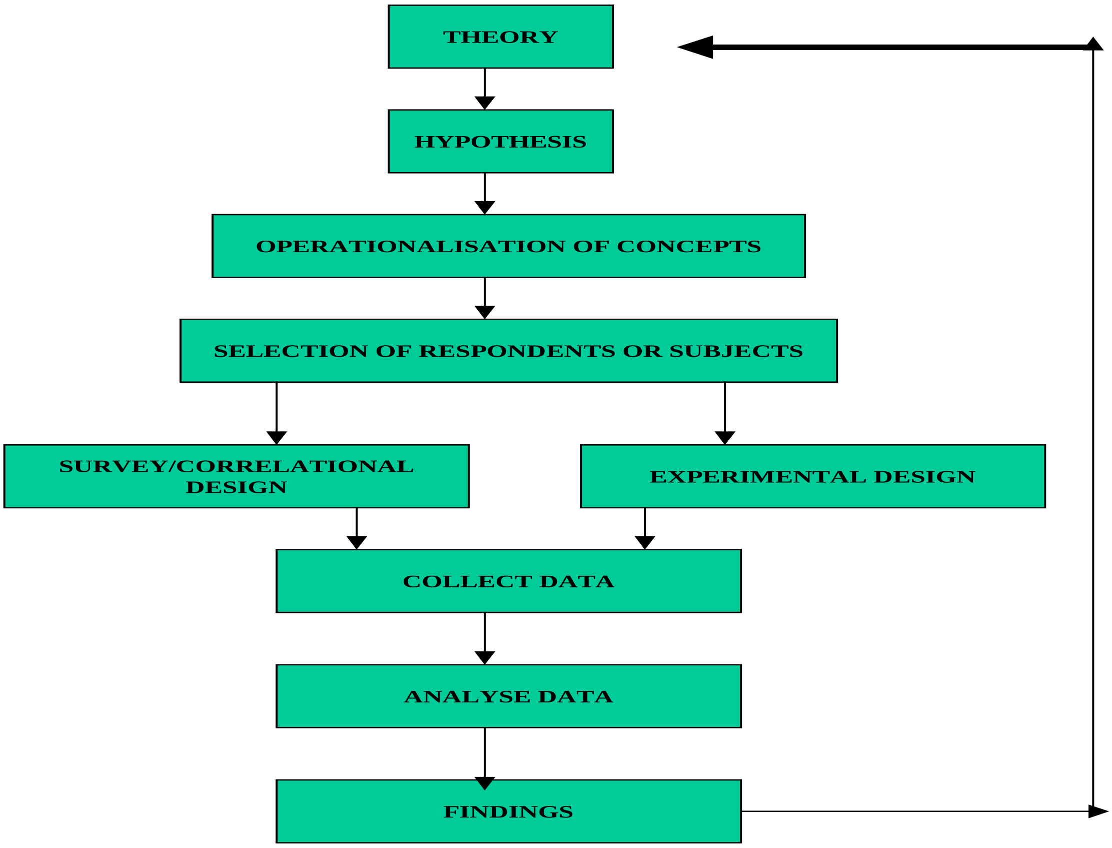


Figure 4.2**: <u>The research process</u>**. Adapted from Bryman (1988).

Figure 4.2 depicts the research process applied for obtaining and analysing data. Table 4.2 summarises the main sections of Figure 4.2.

Research Process	**Notes**
Theory	This is the starting point for the research process.
Hypotheses	Often take the form of relationships between two or more entities/concepts. They force the researcher to think systematically about what is being studied.
Selection of respondents or subjects	This is dependent on the data collection technique being employed.
Research design	Two basic types (1) Experimental design, (2) Survey design. The nature of research design is usually known from the onset of the project.
Collection and analysis of data	Data is collected by the researcher. Analysis can be univariate, bivariate or multivariate.
Findings	The analysis of the data helps to prove or disprove the hypothesis that was outlined at the start of the research.

Table 4.2: **<u>Research process outlined.</u>** Summary points taken from the research process shown in Figure 4.2 (Merton, 1967 and Bryman, 1988)

When working with quantitative data and quantitative analysis techniques there are a few considerations that the researcher should be aware of during the process. These are outlined in the Table 4.3.

Considerations
• Have you answered your research question? • Have you presented information that is relevant to your research? • Have you taken into account the nature of the variable(s) being investigated? • Have you used the most appropriate techniques for answering the research questions? • Have you listed any limitations faced during the collection and analysis of the data? • Have you stated any assumptions made during the research?

Table 4.3: Considerations that should be adhered to during quantitative research (adapted from Bryman, 2004)

4.1.2 Qualitative research

Qualitative research is a research strategy that usually emphasises words rather than quantification in the collection and analysis of data. As a research strategy it is inductivist, constructionist, and interpretivist, but qualitative researchers do not always subscribe to all three of these features (Silverman 1993 and 2004; Bryman, 2004).

Quantitative research is often contrasted with qualitative research, which is the non-numerical examination and interpretation of observations for the purpose of discovering underlying meanings and patterns of relationships (Burgess, 1995; Bryman *et al*, 1994; Bryman, 1995). Qualitative research is generally considered to be explanatory and inductive in nature. It is used to get a general sense of what is happening and for theories that can be further tested using quantitative research, which is viewed as confirmatory and deductive by its nature. In the social sciences, qualitative research methods are often used to gain better understanding of intentionality and meaning (Tesch, 1990).

Qualitative researchers concern themselves with observations of research phenomena *in situ*; that is, within their naturally occurring contexts (Wolcott, 1990 and 1994).

One aim of the qualitative researcher is to tease out the meanings that the phenomena have for the actors or participants (Silverman, 1993).

Wolcott (1990) describes four basic data gathering techniques: *participant observation, interview, open questions* and *document/artifact analysis*. Direct observation should also be considered.

Qualitative research tends to be concerned with words rather than numbers, but three further features are particularly noteworthy (Bryman, 1998 and 2004):

1. An inductive view of the relationship between theory and research, whereby the former is generated out of the latter.
2. An epistemological position described as interpretivist, meaning that, in contrast to the adoption of a natural scientific model in quantitative research, the stress is on the understanding of the social world through examination of the interpretation of that world by its participants.
3. An ontological position described as constructionist, which implies that social properties are outcomes of the interactions between individuals, rather than phenomena 'out there' and separate from those involved in its construction.

Bryman and Burgess (1999) observe that although there has been a proliferation in writing on qualitative research, the research strategy is still hard to fully pin point and define. They propose three reasons for this state of uncertainty:

1. As a term, 'qualitative research' is sometimes taken to imply an approach to social research in which quantitative data are not collected or generated. Many writers on qualitative research are critical of such a rendition of qualitative research, because the distinctiveness of qualitative research does not reside solely in the absence of numbers.
2. Several different traditions in qualitative research can be identified (refer to Table 4.4). These have been suggested by Gubrium and Holstein (1997).
3. Sometimes, qualitative research is discussed in terms of the ways in which it differs from quantitative research. A potential problem with this tactic is that it

means that qualitative research ends up being addressed in terms of what quantitative research is *not*.

Four traditions of qualitative research as identified by Gubrium and Holstein (1997)
• Naturalism – seeks to understand social reality in its own terms; 'as it really is'; provides rich descriptions of people and interactions in natural settings. • Ethnomethodology – seeks to understand how social order is created through talk and interaction; has a naturalistic orientation. • Emotionalism – exhibits a concern with subjectivity and gaining access to 'inside' experience, concern with the inner reality of humans. • Postmodernism – there is an emphasis on 'method talk'; sensitive to the different ways social reality can be constructed.

Table 4.4: The traditions of qualitative research (Gubrium and Holstein, 1997)

Concerns arise when classifying and defining qualitative research because of the various approaches that can be applied by the technique. There is a diverse range of methods, most of which fall under the following five approaches.

- *Ethnography/Participant observation* – It is important to be cautious in treating ethnography and participant observation as synonyms. In many respects they refer to similar if not identical approaches to data collection in which the researcher is immersed in a social setting for some time in order to observe and listen with the view to gaining an appreciation of the culture of a social group.

- *Qualitative Interviewing* – This is a very broad term to describe a wide range of interviewing styles (structured, unstructured, intensive, in depth, focused, group and life/oral history interviews). Qualitative researchers employing ethnography or participant observation typically engage in a substantial amount of qualitative interviewing.

- *Focus Groups* – This is a term devised by Merton *et al* (1956) to refer to an interview using predominantly open questions to ask interviewees (a group of people) questions about a specific situation or event that is relevant to them and of interest to the researcher.

- *Language based approaches to the collection of qualitative data* – such as discourse and conversation analysis.

- *The collection of qualitative analysis of texts and documents.*

The main steps involved in qualitative research are outlined in Figure 4.3

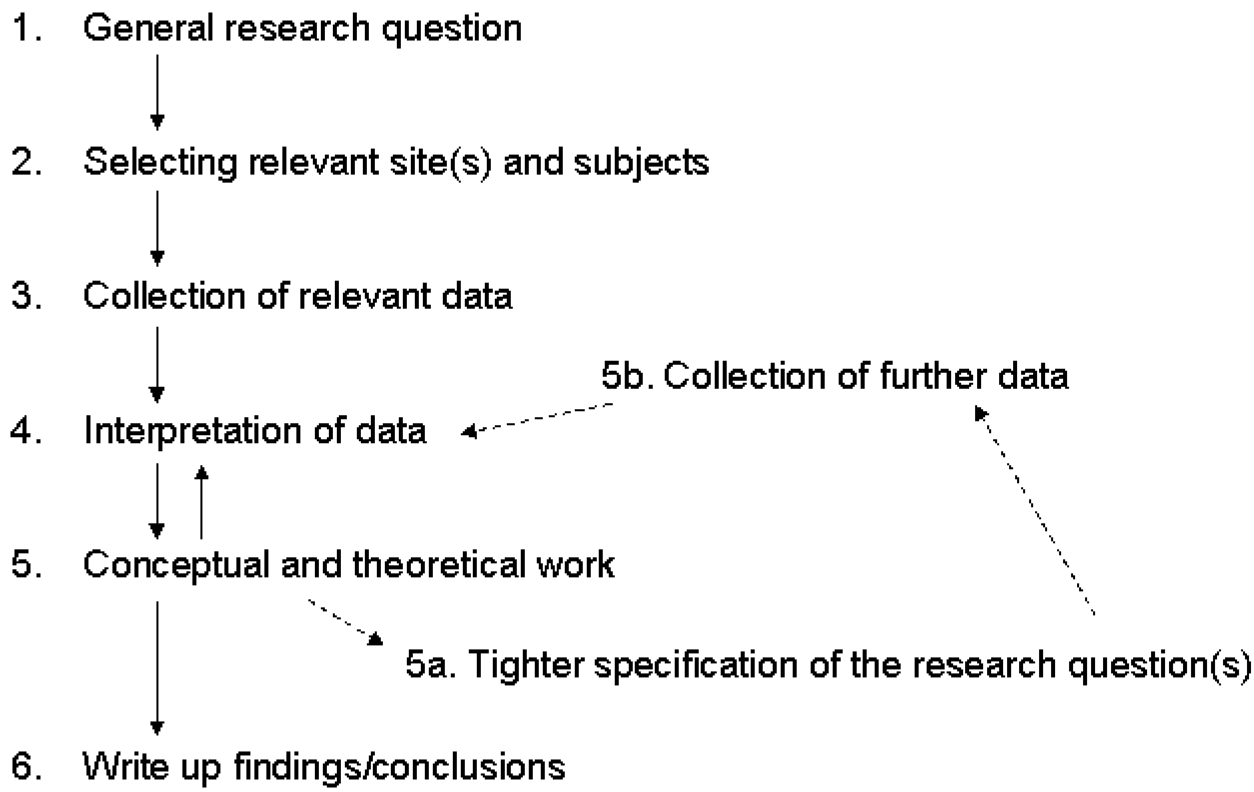


Figure 4.3: The steps involved in qualitative research (Bryman, 2004)

Two aspects of this flow of events for qualitative research require further consideration. These are the issues and links between *theory* and *concepts*. Most qualitative researchers when writing about their craft emphasise a preference for treating theory as something that emerges out of the collection and analysis of data. It is also argued that qualitative data can and should have an important role in relation to the testing of theories. Silverman (1993) states that in more recent times, qualitative researchers have become increasingly interested in the testing of theories and that this is a reflection of the growing maturity of the strategy. There is no reason why qualitative research cannot be employed in order to test theories that are specified in advance of data collection. Qualitative research tends to entail the testing of theories during the research process. On the other hand, for most qualitative researchers, developing measures of concepts will not be a significant consideration. However, concepts are very much part of the landscape in qualitative research. A ‘concept’ is a name given to a category that organises observations and ideas by virtue of their possessing common features (Bryman, 2004). The way in which concepts are developed and employed within qualitative research is often different from that implied by quantitative research strategies. Blumer’s (1954) distinction between ‘definitive’ and ‘sensitising’ concepts captures aspects of the different ways in which concepts are thought about. Blumer (1954) believed concepts should be employed in such a way that they give a very general sense of what to look for and act as a means for uncovering the variety of forms that the phenomena to which they refer can assume. There are however problems with Blumer’s distinction, and the idea of concepts and theories are an ongoing debate in the world of qualitative research.

Qualitative procedures stand in stark contrast to the methods of quantitative research. Qualitative enquiry employs different knowledge claims, strategies of enquiry and methods of data analysis (Coyle *et al*, 2000). Although the processes are similar, qualitative procedures rely on text and image data, have unique steps in data analysis, and draw on diverse strategies of inquiry.

Creswell (1998 and 2003) expresses how qualitative research takes place in the natural setting. This enables the researcher to develop a level of detail about the individual or place and to be highly involved in actual experiences of the participants. Qualitative research is fundamentally interpretive. This means that the researcher makes an interpretation of the data. It also means that the researcher filters the data through a personal lens that is situated in a specific socio-political and historical moment. One cannot escape the personal interpretation brought to qualitative data analysis.

There are four main qualitative data collection methods as outlined by Bogdan *et al* (1979 and 1982) and Creswell (2003); each of which rely heavily on subject participation. Table 4.5 below details these four approaches – observations, interviews, documents and audiovisual materials – and gives further notes surrounding their application (advantages and limitations).

Method	Options	Advantages	Limitations
Observations	• Complete participant • Observer as participant • Participant as observer: observation role secondary to participant role • Complete observer: researcher observes without participating	• Researcher has a firsthand experience with participants • Researcher can record information as it is revealed • Unusual aspects can be noticed during observation • Useful in exploring topics that may be uncomfortable for participants to discuss	• Researchers may be seen as intrusive • "Private" information may be observed that the researcher cannot report • Researcher may not have good attending and observing skills • Certain participants may present special problems in gaining rapport
Interviews	• Face to face: one on one, in person interview • Telephone • Group: researcher interviews participants in a group	• Useful when participants cannot be observed directly • Participants can provide historical information • Allows researcher "control" over the line of questioning	• Provides "indirect" information filtered through the views of interviewees • Provides information in a designated "place" rather than the natural field setting • Researcher's presence may bias responses • People are not equally articulate and perceptive
Documents	• Public documents such as minutes of meetings, and newspapers • Private documents such as journals, diaries, and letters • E-mail discussions	• Enables a researcher to obtain the language and words of participants • Can be accessed as a time convenient to the researcher – an unobtrusive source of information • Represents data that are thoughtful, in that participants have given attention to compiling it • As written evidence, it saves a researcher the time and expense of transcribing	• May be protected information unavailable to public or private access • Requires the researcher to search out the information in hard-to-find places • Requires transcribing or optically scanning for computer entry • Materials may be incomplete • The documents may not be authentic or accurate
Audiovisual materials	• Photographs • Videotapes • Art objects • Computer software • Film	• May be unobtrusive method of collecting data • Provides and opportunity for participants to directly share their "reality" • Creative in that it captures attention visually	• May be difficult to interpret • May not be accessible publicly or privately • The presence of an observer may be disruptive and affect responses

Table 4.5: **Qualitative research methods, advantages and limitations** (Creswell, 2003)

4.13 Contrasts between quantitative and qualitative research

Before moving on to discuss and highlight the concept of 'multi-strategy methods' for research and the combining of quantitative and qualitative data, outlined below are some contrasts between quantitative and qualitative research that should be noted.

Table 4.6 attempts to highlight some of the chief contrasting features between quantitative and qualitative research as documented by Halfpenny (1979), Bryman (1988) and Hammersley (1992).

QUANTITATIVE	QUALITATIVE
Numbers	Words
Point of view of researcher	Points of view of the participants
Researcher distant	Researcher close
Theory testing	Theory emergent
Static	Process
Structured	Unstructured
Generalisation	Contextual understanding
Hard, reliable data	Rich, deep data
Macro	Micro
Behaviour	Meaning
Artificial settings	Natural settings

Table 4.6: Simple contrasting points between quantitative and qualitative research

Each of the contrasting points stated in Table 4.6 shall now be discussed. This information has been adapted from Bryman, 2004.

Contrasting Point	Notes
Numbers vs. Words	Quantitative researchers are often portrayed as applying measurement procedures to social life, while qualitative researchers are seen as using words in the presentation of analyses of society.
Point of view of researcher vs. Point of view of participant	In quantitative research, the investigator is in the driving seat. In qualitative research, the perspective of those being studied – what they see as important and significant – provides the point of orientation.
Researcher is distant vs. Researcher is close	In quantitative research, researchers are uninvolved with their subjects. This lack of contact with subjects is regarded as desirable by quantitative researchers, because they feel their objectivity might be compromised if they become too involved with the people they study. The qualitative researcher seeks close involvement with the people being investigated, so that he or she can genuinely understand the world through their eyes.
Theory and concepts tested in research vs. Theory and concepts emergent from data	Quantitative researchers typically bring a set of concepts to bear on the research instruments being employed, so that theoretical work precedes the collection of data, whereas in qualitative research concepts and theoretical elaboration emerge out of data collection.
Static vs. Process	Quantitative research is frequently depicted as presenting a static image of social reality with its emphasis on relationships between variables. Change and connections between events over time tend not to surface, other than in a mechanistic fashion. Qualitative research is often depicted as attuned with the unfolding of events over time and to the interconnections between the actions of participants of social settings.
Structured vs. Unstructured	Quantitative research is typically highly structured so that the investigator is able to examine the precise concepts and issues that are the focus of the study. In qualitative research the approach is invariably unstructured, so that the possibility of getting at actors' meanings and of concepts emerging out of data collection is enhanced.
Generalisation vs. Contextual understanding	Whereas quantitative researchers want their findings to be generalisable to the relevant population, the qualitative researcher seeks an understanding of behaviours, values, beliefs, and so on in terms of the context in which the research is conducted.
Hard, reliable data vs. Rich, deep data	Quantitative data are often depicted as being 'hard' in the sense of being robust and unambiguous, owing to the precision offered by measurement. Qualitative researchers claim, by contrast, that their contextual approach and their often prolonged involvement in a setting engender rich data.
Macro vs. Micro	Quantitative researchers are often depicted by those writing about the subject, as involved in uncovering large-scale social trends and connections between variables, whereas qualitative researchers are often seen as concerned with small-scale aspects of social reality, such as interaction.
Behaviour vs. Meaning	Bryman (2004) suggests that the quantitative researcher is concerned with people's behaviour and the qualitative researcher with the meaning of the action.
Artificial settings vs. Natural settings	Whereas quantitative researchers conduct research in a contrived context, qualitative researchers investigate people in natural environments.

Table 4.7: Comparison between quantitative and qualitative data research

Further comparisons between quantitative and qualitative data have been made by Bryman (2000). Table 4.8 compares quantitative and qualitative research – adapted from Bryman (2000). The eight points listed are deemed to highlight where the two research traditions diverge.

Dimension	Quantitative	Qualitative
Role of qualitative research	Preparatory	Means to exploration of actors interpretations
Relationship between researcher and subject	Distant	Close
Researcher's stance in relation to subject	Outsider	Insider
Relationship between theory/concepts and research	Confirmation	Emergent
Research strategy	Structured	Unstructured
Scope of findings	Nomothetic	Ideographic
Image of social reality	Static and external to actor	Processual and socially constructed by actor
Nature of data	Hard, reliable	Rich, deep

Table 4.8: **Comparisons between quantitative and qualitative research**. (Adapted from Bryman, 2000)

View of the role of qualitative research

Qualitative research is seen by social scientists as useful at the preparatory stage of a research project (Bryman, 2000). The explorative and unstructured approach to qualitative research is often depicted by social scientists as a useful means to throwing up hunches and hypotheses, which can be tested more rigorously by quantitative research. Views are influenced by the purpose of the research, the preferences and interests of the researcher, and the target audience of the research.

Relationship between researcher and subject

In quantitative research, the researcher's contact with the people being studied is often fairly remote. Although the data collection phase tends to be extensive, contact with individuals is usually brief. Sometimes, quantitative research does not require contact with the subjects. By contrast, qualitative research entails much more sustained contact, especially when participant observation is the central method.

The researcher's stance in relation to the subject

The quantitative researcher adopts the posture of an outsider looking in on the social world. The researcher applies a pre-ordained framework on the subjects being investigated and is involved with the subjects as little as possible. Among qualitative researchers there is a strong urge to 'get close' to the subjects being investigated – to be an insider. For qualitative researchers, it is only by getting close to their subjects and becoming an insider that they can view the world as a participant in that setting. Problems can arise from this approach, such that the researcher may become too involved with the perceptions of the participants that they lose perspective towards the research.

Relationship between theory/concepts and research

Figure 4.4 below highlights how theories and concepts are the starting points for quantitative investigations.

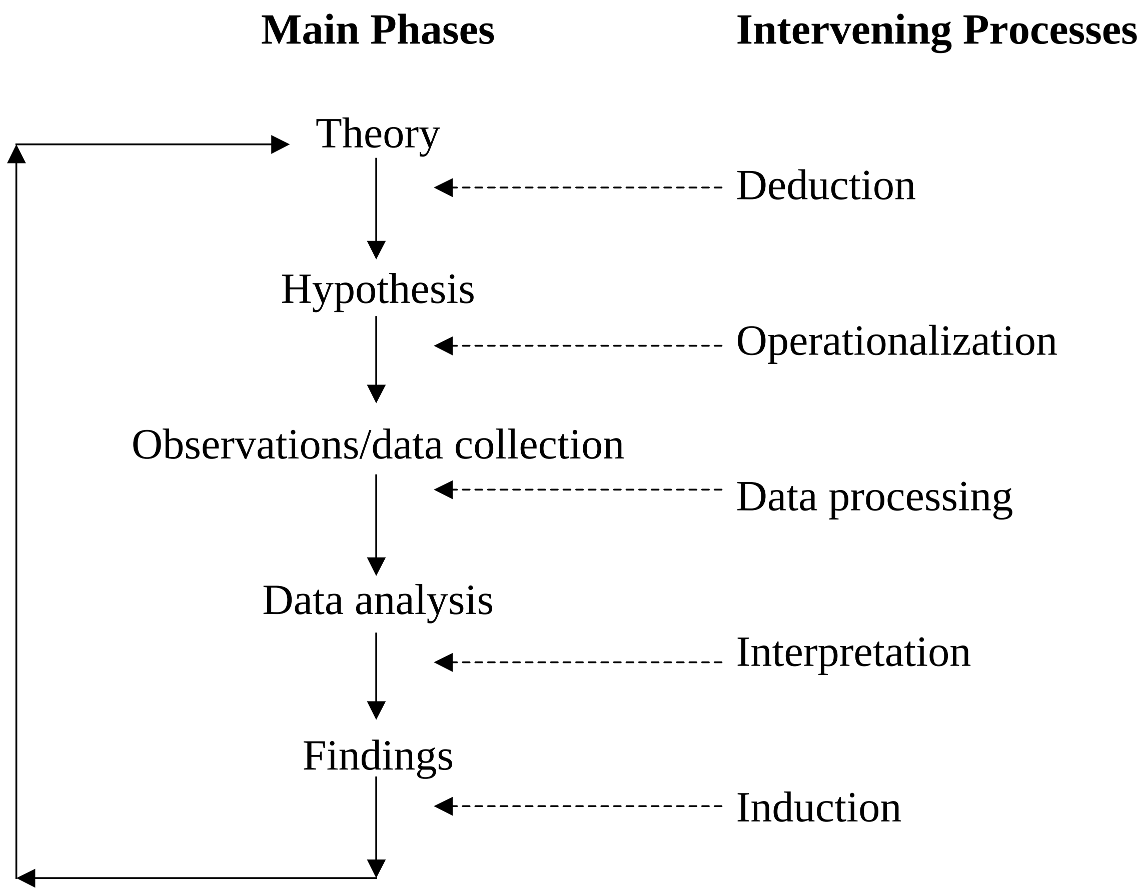


Figure 4.4: **Quantitative research process** (Bryman, 2000; Tufte, 2004)

By contrast, qualitative researchers often reject the idea of using theory as a precursor to an investigation, since it may not reflect subjects' views about what is going on and what is important (Bryman, 2000).

Research Strategy

Quantitative research tends to adopt a structured approach to the study of society. This tendency is a product of the methods with which it is associated – surveys and experiments are required to be focused from the outset. Qualitative research tends to be more open, affected by being in the right place at the right time.

Scope of findings

It is common to conceive the quantitative/qualitative dichotomy in terms of respective commitments to nomothetic and ideographic modes of reasoning (Bryman, 2000). This distinction effectively refers to the scope of the findings, which derive from a piece of research. A nomothetic approach seeks to establish general law-like findings, which can be deemed to hold irrespective of time and place. An ideographic approach locates its findings in specific time periods and locales. Qualitative research often refers to case studies whose representativeness is unknown; hence the generalisability of findings is also unknown. The extent of 'randomness' used in quantitative research is often limited as the samples and surveys often refer to highly restricted populations. Experimental research also suffers from a number of deficiencies in regard to the "generalisability" of findings stemming from such design (Bryman, 2000). Caution is required when treating the two research traditions as being strictly associated with nomothetic and ideographic findings.

Image of social reality

Quantitative research conveys a view of social reality which is static in that it tends to neglect the impact and role of change in social life (Bailey *et al*, 1999). Surveys examine co-variation among variables at a particular juncture; experimental research usually entails the exploration of a restricted range of variables within a restricted time period. While both styles of research examine connections between variables, the proponents of qualitative research argue that quantitative research rarely examines the processes that link them. The qualitative researcher is in a better position to view the linkages between events and activities and to explore people's interpretations of the factors that produce connections. This stance affords the qualitative researcher a much greater opportunity to study processes in social life.

In addition to their respective tendencies to convey static and processual views of social life, quantitative and qualitative research differ in their view of the mutual relationship between the individual and social reality. There is a tendency for quantitative researchers to view social reality as external to actors and as a constraint on them, which can be attributed to the preference for treating the social order as though it were the same as the objects of the natural scientists (Bryman, 1995 and 2000; Bailey *et al*, 1999). By contrast, the influence of perspectives like phenomenology, symbolic interactionism, and naturalism led qualitative researchers to suggest that “we cannot take for granted, as the natural scientist does, the availability of a preconstituted world of phenomena for investigation,” but must “examine the processes by which the social world is constructed.” (Walsh, 1972). Thus, whereas quantitative research tends to invoke a perspective which implies that social reality is static and beyond the actor, the image deriving from qualitative research gives a sense of that same reality in processual terms and as socially constructed.

Nature of the data

The data emanating from quantitative studies are often depicted as hard, rigorous, and reliable. These adjectives suggest that such data exhibit considerable precision, have been collected by systematic procedures and may be readily checked by another investigator. These positive attributes are often taken to mean that quantitative data are more persuasive and hence more likely to gain the support of policy makers.

Qualitative researchers routinely describe the data deriving from ethnographic work as ‘rich’ and ‘deep’, often drawing a contrast with quantitative data, which tend to be depicted as superficial. The denotation ‘rich’ refers to the attention to detail often observed by qualitative researchers.

It should be concluded however, that the statements above that illustrate the contrasts between quantitative and qualitative research, should not be viewed as constituting hard and fast distinctions.

4.1.4 Multi-strategy Methods

By combining quantitative and qualitative strategies one would assume the researcher can capitalise on all the strengths of the two accolades, and offset any weaknesses. However there is much scepticism surrounding this concept. Since the early 1980s the amount of combined research has been increasing.

Multi-strategy methods employ both qualitative and quantitative approaches. A multi-strategy research problem may be one in which a need exists to both understand the relationship among variables in a situation and explore the topic in further depth. It may initially seek to explain the relationships between variables, and then explore the views towards the variables.

Within this section, three areas can be discussed:

1. Arguments against integrating quantitative and qualitative research
2. Different combination ways
3. Assessment of the need to use the methods.

The argument against the combination of research methods to form a multi-strategy tends to be based on either or both of the following arguments:

- The idea that research methods carry epistemological commitments
- The idea that quantitative and qualitative research are separate paradigms

The first point implies that research methods are rooted in epistemological (acceptable knowledge) and ontological (theory of the nature of social entities) commitments. Such a view of research methods can be discerned in statements such as the following taken from Hughes (1990) "*every research tool or procedure is inextricably embedded in commitments to particular versions of the world. To use a questionnaire, to use an attitude scale, to take the role of participant observer, to select a random sample, to measure rates of population growth, and so on, is to be involved in conceptions of the world which allow these instruments to be used for the purposes conceived*".

Therefore it can be said that the decision to employ, for example, participant observation is not simply about how to go about data collection but a commitment to an epistemological position that is opposed to positivism and that is consistent with interpretivism. This kind of view has led some writers to argue that a multi-strategy research approach is not feasible or desirable.

A paradigm is a term deriving from the history of science where it was used to describe a cluster of beliefs and dictates that for scientists in a particular discipline influence what should be studied, how research should be done, and how results should be interpreted. The paradigm argument conceives of quantitative and qualitative research as *paradigms* in which epistemological assumptions, values, and methods are inextricably interwined and are incompatible between paradigms (Guba, 1985; Morgan, 1998). Therefore, when researchers combine participant observation with a questionnaire, they are not really combining quantitative and qualitative research, since the paradigms are incommensurable. The integration is only at a superficial level. However, as Kuhn (1970) argues, it is by no means clear that quantitative and qualitative research are in fact paradigms, as there are areas of overlap and commonality between them.

The debate surrounding the combining of quantitative and qualitative research centres on two versions related to the nature of research. The first version – epistemological – as mentioned above expresses how multi-strategy research is not a feasible option. However, the second version – technical – gives greater prominence to the strengths of the data collection and data analysis techniques with which quantitative and qualitative research are each associated and sees these as capable of being fused. Within the technical version, there is recognition that quantitative and qualitative research is connected with distinctive epistemological and ontological assumptions but the connections are not viewed as fixed. Research methods are perceived as autonomous. A research method from one strategy is viewed as capable of being pressed into the service of another. The technical views the two research strategies as compatible. As a result, multi-strategy research becomes both feasible and desirable.

Hammersley (1996) has proposed three approaches to multi-strategy research:

- *Triangulation.* This refers to the use of quantitative research to corroborate qualitative research findings or vice versa.
- *Facilitation.* This approach arises when one research strategy is employed in order to aid research using the other research strategy.
- *Complementarity.* This approach occurs when the two research strategies are employed in order that different aspects of an investigation can be merged.

Scientific researchers need to convey the specific strategy for data collection they plan to use. Criteria can also be identified related to the strategies used. The matrix shown in Figure 4.5 illustrates the four decisions that go into selecting a multi-strategy research method of inquiry (Creswell, 2003).

Implementation	**Priority**	**Integration**	**Theoretical Perspective**
No sequence concurrent	Equal	At data collection	Explicit
Sequential-Qualitative 1st	Qualitative	At data analysis	
Sequential-quantitative 1st	Quantitative	At data interpretation	Implicit
		With some combination	

Figure 4.5: **Multi-strategy method decision-making matrix.** Four decisions that go into selecting a mixed methods approach (Creswell, 2003)

From this matrix four questions can be asked related to the four premises for multi-strategy applications.

1. What is the implementation sequence of the quantitative and qualitative data collection in the proposed study?
2. What priority will be given to the quantitative and qualitative data collection and analysis?
3. At what stage in the research project will the quantitative and qualitative data and findings be integrated?
4. Will an overall theoretical perspective be used in the study?

The importance of mixing research strategies is to help increase awareness and understanding of human perceptions towards potential outcomes from research. Integration helps to increase the scope of the research and the potential outcomes available.

There is little doubt that multi-strategy research is becoming more common (Bryman, 2004). Two particularly significant factors in prompting this development are:

- A growing preparedness to think of research methods as techniques of data collection or analysis that are not encumbered by epistemological and ontological baggage as is sometimes supposed.
- A softening in the attitude towards quantitative research among feminist researchers, who had previously been highly resistant to its use.

It is important however to realise that multi-strategy research is not intrinsically superior to mono-method or mono-strategy research. It should not be considered as an approach that is universally applicable. It may provide a better understanding of a phenomenon than if just one method is used, and it may frequently enhance our confidence in the research findings. This is often dependent on the actual research being performed and on the researcher. The general point remains, that multi-strategy research, while offering great potential in many instances, is subject to similar constraints and considerations as research relying on a single method or research strategy.

A combination of qualitative and quantitative research approaches have been adopted for the production of the Tanzanian DSS and a strategy for amalgamating the methods can be outlined.

4.2 Methods used for the Tanzanian Project

With regard to the Tanzanian scenario it is evident that both qualitative and quantitative information is required for the development of the DSS for RWH management. Relationships and hence numerical data are required for building a model that is capable of making yield predictions for two crops (rice and maize) at different levels of water and nutrient application. An understanding of wealth status and existing conditions/management approaches is also required to help determine the best management strategies for the individuals or communities in Tanzania.

The strategies applied for the acquisition of qualitative and quantitative information for the Tanzanian project shall now be outlined.

4.2.1 Qualitative Research

Four approaches to qualitative research have been applied for the study described in this thesis:

1. Questionnaires – formulation of databases
2. Focus groups – survey information
3. GIS systems – general observations
4. Participatory rural appraisal (PRA) – ranking procedures and observational information (Davies *et al*, 1999)

The methods were carried out by the agricultural scientific extension officers in the study regions. A structured approach was determined by both partners in Tanzania and Nottingham.

The purpose of applying these techniques was to determine details surrounding existing conditions and management practices in the two study regions. The information helped in determining wealth categorisations.

Table 4.9 below highlights some of the initial thinking behind the application of techniques and the information collected.

Research technique	**Information collected**	**Format and collected by**
Questionnaires	General characteristics – age, sex, profession, residence etc.	Extension officers in the field and documented in tables
Focus groups	Perceptions. Wealth ranking criteria. Determination of existing management conditions and farming practices.	Extension officers. Small meetings held with groups of stakeholders. Information recorded in reports and tabulated.
GIS systems	Development of maps: Highlight conditions of the two study regions. (Cropping practices and specific local infrastructure.)	Observational surveys and questioning of stakeholders. Maps produced using GIS computer systems such as ArcView.
Participatory Rural Appraisal (PRA)	Formulation of criteria used for ranking procedures. Determining which criteria are of most importance. Splitting of the wealth ranking into different headings. Obtaining general feedback and information on CPR used by local people.	Discussions and different PRA techniques such as the use of ranking cards and the assigning of levels of preference. Information presented in tables and written reports and via verbal communication.

Table 4.9: **Qualitative information methods.** Brief description of the information collected by the methods of qualitative research applied

4.2.1.1 Questionnaires and Focus Groups

A questionnaire was compiled by the Tanzanian extension officers and Nottingham team. The objective of the questionnaire was to determine population details for the study regions as well as current management systems performed by the stakeholders.

For both regions a multistage sampling technique was adopted. Since the whole of Maswa district is categorized as semi-arid, all 78 villages were included in the study. For the WPLL, stage one entailed selection of villages. Thirty-seven villages (25 in Mwanga District and 12 in Same District) were selected for study in WPLL. These included all the villages on the western side of the two districts that are categorized as semi-arid by the District Agricultural Office. (Kajiru *et al*, Personal Communication, 2000)

Data collection was achieved through interviews and focus groups with key informants. Key informants were people who are assumed to be knowledgeable in RWH practices in their villages. Village leaders and extension staff at ward and village levels constituted the focus groups. The SUA research team helped to conduct these focus groups. Members of the team included Geophrey Kajiru and Abeid Msangi.

Focus group meetings were held at ward level, grouping together several villages. There were two separate sessions of about three hours for each ward. The first session brought together village leaders and extension staff. The second session involved only the village leaders. Therefore meetings involved 10 to 15 key informants. Researchers from SUA explained the objective of the survey to the participants. Collected information included: demographic characteristics, land use, agricultural and livestock production activities, rainfall characteristics, water availability for different uses, and the potential for RWH. Techniques of RWH currently in use, areas and activities where RWH is mostly practiced and areas suitable for RWH for various activities were identified.

4.2.1.2 Geographical Information Systems (GIS)

Geographical Information Systems (GIS) have been applied as another tool for representing the collected survey data surrounding the two study regions. It has enabled the production of maps that illustrate farming practices across villages and highlight the existing infrastructure of villages.

Information was collected by Ludovic (2003) through surveys and observational research carried out by the extension officers and SUA team in the study regions. The collected information was subsequently inputted within GIS software for the development of the maps.

4.2.1.3 Participatory Rural Appraisal (PRA)

Many PRA techniques including the use of secondary sources, key informant informal interviews, group discussions and air photo analysis have a long history. Others are continuing to evolve as the approach is used in more diverse environments.

The main advantage of PRA is that it is quicker, cheaper and more adaptable than traditional research methods (Agarwal, 2001). The technique focuses on groups rather than individuals. This improves the data gathering process by potentially making it more enjoyable. Accuracy is improved as cross-checking occurs naturally. Chambers (1989 and 1992) argues that this results in PRA being a much more personal process that helps to enhance the control of development.

Issues do arise with the application of PRA. Simply, if the chosen approach is wrong, then it will not work. The attitudes and behaviour of the participants in the process are key to the success of the approach.

One key factor for the application of PRA techniques is that the participants have knowledge and a history of working with extension officers, NGOs and researchers as this will enable the techniques to be easily adopted and incorporated into the study. This knowledge was present for the Tanzanian study, as research into RWH management systems has been taking place there for the past fifteen years.

It was necessary to determine from the stakeholders what factors in their view influence the wealth of a person. These factors were determined for the different villages in the study regions and for the various professions of stakeholders. This brought about the formulation of many tables highlighting the criteria involved and the importance of each criterion for three wealth rankings – rich, middle and poor status.

PRA techniques were applied by the SUA team (Msangi, Personal Communication, 2002, 2003) for the determination of conditions and for understanding local infrastructure in the study regions. The techniques involved asking stakeholders to draw representative maps detailing what they think their village is like. These were subsequently copied by the extension officers and recorded to help in producing the GIS maps.

4.2.2 Quantitative Research

The quantitative data collected for the Tanzanian project is focused upon agricultural traits, such as yields and levels of resources applied and the subsequent effects on crop yields. Climatic and topographic details are of importance as well, much of which has been made available via the use of historical data and through observations and discussions with the stakeholders in the field.

The application of quantitative information for the development of the DSS adds another dimension to the decision-making processes that can be included within the system. Predictive and quantitative models can be applied that can help to detail outputs that can highlight potential benefits from applying certain management interventions. Numerical data and models also help to add confidence to the options that can be determined from the overall system (Davis, 1999).

The methods used for collecting data for analysis and model/relationship building were as follows.

- Experimental work – Field trials (cropping systems), physical and chemical data collection (soil profiling) carried out by the research team at SUA.
- Use of existing agricultural models such as PT. This research was carried out by both the SUA team and the team in Nottingham.
- GIS – and observations. Carried out by the SUA team and extrapolated to the team in Nottingham for further manipulation.
- Statistical manipulations – following the acquisition of information. Information was sent through to the team in Nottingham via Email (Word documents and Excel tables) and reports. Much of the data was in its raw format and had to be sorted by the team in Nottingham and cross-checked again with the SUA team. Manipulation and utilisation of the data was then

carried out by the Nottingham researchers for developing the relationships for the DSS.

The experimental work and GIS/observational research was carried out in Tanzania by the extension officers working in the study regions. Results were conveyed to partners in Nottingham for further analysis and manipulation. The utilisation of existing models for the formulation of data sets was carried out by partners in Nottingham, and verified with partners in Tanzania, to ensure the results and data being extrapolated from the models fitted with the situation in Tanzania.

4.2.2.1 Experimental Work

A limited number of field trials were carried out in the study regions by the SUA team to obtain the yields for rice and maize at varying nutrient levels. Plates 4.1 and 4.2 below highlight the situation for rice and maize respectively.

Plate 4.1: **Rice trials**

Plate 4.2: **Maize trials**

Actual chemical and physical information surrounding the soil types in the study regions were recorded via the use of soil sampling techniques (Kajiru, Personal Communication, 2002).

4.2.2.2 Use of existing models

Within this study, models that tackle crop production and resource management are of particular interest. PT (Parched-Thirst), which was developed from the principles identified in the PARCH model is seen as the most significant and useful model for the purposes of this study as discussed in Chapter Three.

4.2.2.3 GIS and Observations

Physical data that were collected through surveys helped to develop maps that have highlighted topographic and climatic conditions within the study regions. This information can subsequently be modelled within the DSS.

The application of GIS techniques has already illustrated a way in which quantitative and qualitative information can be combined leading to ‘mixed methods’ approaches.

Generic numerical observations were carried out by the extension officers, such as determining the sizes of farms and the numbers of livestock present on a farm. These numerical data were recorded via the use of field notes and subsequently tabulated.

4.2.2.4 Statistical manipulation

The application of statistical tests as highlighted by Stern (2004), followed the collection of data to ensure reliability in the information collected, before the data were utilised for further model development. These tests were carried out by the team in Nottingham.

The majority of the numerical data were tabulated by the SUA team of researchers and extrapolated to the team in Nottingham for further analysis using computer programs such as Microsoft Excel. Other information had to be grouped together to enable suitable analysis to be performed.

4.2.3 Importance of the numerical and social data collected for the development of the Tanzanian DSSs

Norton (1995) proposes a relationship between crop research, agroecological research and agropolicy research. Interactions between these three levels take stock of numerical and social data both of which were fundamental for the development of the Tanzanian DSS. Figure 4.6 highlights this relationship.

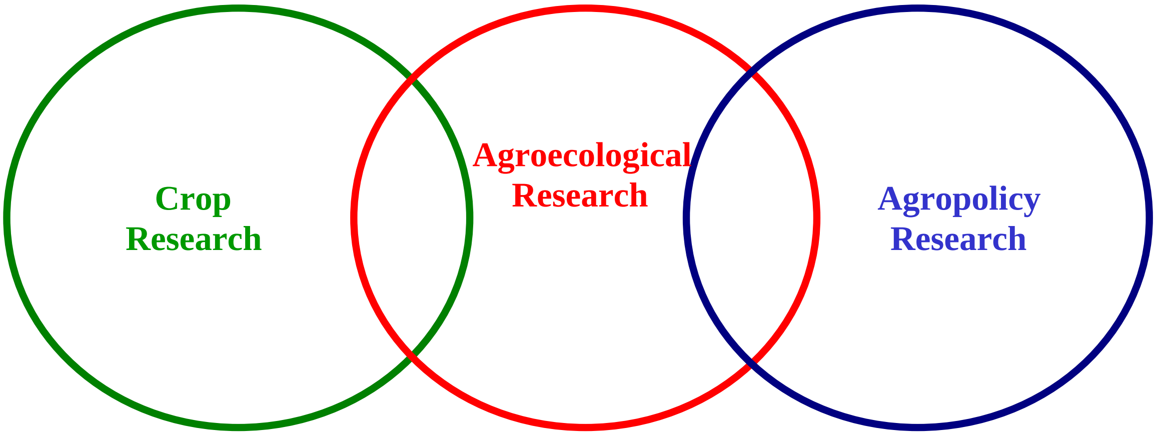


Figure 4.6: The relationship between crop research, agroecological research and agropolicy research as proposed by Norton (1995)

In the context of this study into RWH management and the development of a DSS, numerical relationships can be derived during crop research in relation to crop productivity and supplied resources. Agroecological research focuses upon the impact of the crop research and brings in other environmental factors that should be considered related to topographic studies and climatic influences. There is a crossover with crop research and agropolicy research. Agropolicy research focuses upon the social issues and constraints that influence management decisions (Norton, 1995). Principally, this is where the non-numerical data is focused and is established for the development of management DSSs. An understanding of governmental and management policies aids in the uptake and extrapolation of new management approaches.

The research carried out for the development of the Tanzanian DSS and subsequently for the development of a single strategy for DSS development, tackled both forms of data. These data streams shall now be discussed in relation to the development of the Tanzanian DSS and how they have been incorporated within the strategy for DSS development.

In summary, the predominant forms of data capture were through existing models that were able to generate data sets that covered a 30-year period for the study regions in Tanzania. The model used was PT. The data extrapolated from this model were analysed against the limited field data collected. Regression analyses were performed to help ensure agreement between predicted and expected yield performances based upon varying levels of water and nutrients. These numerical data were then utilised for building the mathematical relationships between water/nutrients and their effects on crop growth. The derived relationships were cross-referenced with those found in the literature for resource capture and utilisation (Loomis *et al,* 1998; Meinzen-Dick *et al,* 2002).

From the data requirements (Table 4.10) it was possible to determine the parameters that were required for building the Tanzanian DSS. Listing the required parameters in a table helped to add focus to the data gathering process. This is one area that is also highlighted within the strategy for DSS development – the Requirements Specification phase. Principally, the main numerical data that were collected were related to levels of rainwater and nutrient (manure) captured and applied, and their underlying effect on the growth of maize and rice.

Basic Information	Types of Information
Basic Maps	- Topography - Settlements - Communication systems - Administrative boundaries
Climatic	- Rainfall, temperature, light intensity, day length, humidity and wind
Land	- Soil (description, classification, mapping, suitability) - Topography (slope classes, physiographic units) - Land units - Land ownership records
Water resources	- Surface water e.g. rivers and flash floods - Subsurface water (extent, yield and quality of aquifers)
Land covers and land use	- Land cover - Land use - Environmental requirements of crops
Population (number and location)	- Human - Farm animals - Wildlife
Social information	- Group (description and classification) - Objectives (land users, community, government) - Resources and constraints
Economic data	- Input costs - Sales price - Transport costs
Physical infrastructure	- Markets and processing plants - Road and railways - Houses - Water reservoir
Institution and legal aspects	- Information on relevant institutions and their responsibilities - Documents of laws applying to relevant aspects of land

Table 4.10: Requirements specification information for the development of new management systems (Hatibu, 2000)

As with the majority of models and DSSs, the numerical data collected by the SUA team were manipulated by the Nottingham team through the development of mathematical relationships to simulate the actual process being modelled. Where the Tanzanian model differs from the standard simulation models (Matthews *et al*, 2002) is that it has incorporated qualitative data borne from social studies of the farmers in the study regions. The collected data have been collated via means of numerical scoring to help integrate them into the development of the Tanzanian DSS.

Table 4.5 illustrates some differences between quantitative and qualitative research – adapted from Bryman (2000). The eight points listed highlight where the two research traditions diverge. Figure 4.4 expresses how the importance of having a structured process flow for the collection of both types of data is of utmost importance (Tufte, 2004).

In planning for RWH systems, it is not enough to just consider the technical and numerical aspects but also the socio-economic environment (Baland *et al*, 1996). The most important components of socio-economic environment are: policy and legal frameworks, local institutions, equity aspects and cost and benefit relationships (Lazaro *et al*, 2000). Each of these aspects shall be explained.

4.2.3.1 Policy and legal framework

When planning and designing strategies for enhancing RWH management, consideration should be placed on the existing policies and laws that govern the various land-use practices such as reserved lands, agriculture and infrastructure. Table 4.11 highlights the considerations that should be made in relation to introducing RWH for agriculture (Lazaro *et al*, 2000; Shrestha, 2003).

Consideration	Evidence and information
Rainfed crop production	Capture rain where it falls - Improving infiltration - Reducing water losses from the root zone - Improving crop water-use and productivity
Runoff farming	This is a major component of RWH for crop production designed specifically to overcome the problem of low amount and/or poor distribution of rainfall. Examples: - Strip catchment tillage - Basin systems - Semi circular hoops - Conservation bench terrace
Floodwater harvesting	Due to the nature of rainfall in semi-arid areas, flash floods are common. Methods for storing this floodwater should be considered. - Cultivated reservoirs - Stream-bed systems - Hillside conduit systems - Ephemeral stream diversion
Agricultural management systems and considerations	Various fields that fall under agricultural management and planning need to be noted when planning RWH management strategies. - Horticulture - Livestock and wildlife - Rangelands The introduction and understanding of common property regimes and common pool resources needs to be applied.
Storage of harvested water	The need for storage is dictated by characteristics of both the runoff and intended use of the water. However, costs prove to be the most limiting factor. An agricultural planner will be faced with 3 important decisions - Is storage necessary? - What storage methods and size should be used? - How should problems associated with storage systems be avoided? The common storage methods applied in Tanzania are: - Excavated bunded basins (Majaluba) - Excavated pits or ponds - Sub-surface sand dams - Low earth dams (Malambo) - Regulating reservoirs There are also problems that are associated with the storage of water that need to be highlighted. - Cost element - Siltation - Evaporation - Seepage - Health hazards

Table 4.11: Considerations for introducing RWH management systems (Adapted from Lazaro, 2000)

Table 4.12 focuses more upon the socio-economic environment and its affects on RWH.

Considerations	Evidence and information
Land Tenure	Land tenure is an important consideration in RWH planning, mainly because it plays a critical role in investments that are related to land use and natural resources management practices. Land tenure is a system of land ownership or acquisition governed by the land laws and prevailing land policies. It is related to rights of occupancy. In Tanzania, the National Land Policy of 1995, the Land Act of 1999 and various customary land tenure systems (URT, 1999; URT, 1995) specifically govern tenure. The policy points clearly to the need for having a clear tenure system as an important factor ensuring both optimal and sustainable use of lands. Land falls under three categories: - General land - Reserved land - Village land
Water Resources	The water policy (1996) in Tanzania put the following emphasis on RWH - Construction of small and large reservoirs in semi arid areas - The use of rooftop RWH - Provision of technical knowledge to the public on the use of small and large reservoirs - Strengthening rainfall data collection

Table 4.12: Socio-economic factors that influence the adoption of RWH strategies

However, qualitative researchers often reject the idea of using theory as a precursor to an investigation, since it may not reflect the subjects' views about what is going on and what is important (Bryman, 2000).

4.2.3.2 Local Institutions

The identification of institutions should be done with the objective of understanding their roles with respect to RWH. Institutions can form a useful entry point for a project and can also be used in the implementation of plans. This was the case for the development of the Tanzanian DSS and the links that were forged with the extension officers in the field and the village elders within the communities for whom the DSS was developed.

Four main categories of institutions can be identified (Table 4.13):

1. Local governments
2. Central government
3. Community based organisations
4. Non-governmental organisations

Category	Comments
Local governments	These institutions include district governments, ward development councils, and village councils. They are important institutions in providing respective guidance on local by laws and management of projects
Central government	These institutions are those that operate as state organs e.g. courts and public schools.
Community based organisations	These are formal and informal organisations which are formed through the community initiatives. Informal organisations include labour sharing groups, women groups and youth groups.
Non-governmental organisations (NGOs)	These are institutions, which are usually registered through the Ministry of Internal Affairs. They include international and local organisations. The mode of operation of NGOs is often based on participatory approaches. NGOs normally have a good and deep insight on the local conditions as well as needs and aspirations of their target beneficiaries.

Table 4.13: Institutions that should be considered when adopting RWH management techniques.

Close affiliation with institutes such as NGOs and community-based organisations has helped in the development of the Tanzanian DSS. Principally these have been the extension officers and the researchers working out of the Sokoine University of Agriculture in Tanzania, with whom Nottingham University was a partner for this research.

4.2.3.3 Equity

For the development of the Tanzanian DSS, equity is used to refer to fairness in the distribution of resources. Four areas are considered

1. Income sources
2. Gender relations
3. Upstream-downstream relationships
4. Crop and livestock relationships

With regard to the Tanzanian DSS it has been fundamental to have an understanding of the social status of the farmers as this influenced the decisions that can be made through the application of the proposed DSS. Knowledge of this nature helped to build the relationships that were implemented within the DSS.

4.2.3.4 Cost and benefit relationships

Cost and benefit relationships (Fischer *et al*, 2002) are important in the adoption of improved RWH techniques. The decision of farmers to adopt RWH like any other investment decision on the farm can be driven by a profit motive but more importantly by subsistence requirements. Components of costs, benefit components, externalities and decision criteria are four areas that need to be considered when determining the cost/benefit affect of applying RWH techniques.

4.3 Limitations of methods

The main limitation that arose for the collection of data was acquiring physical data for yields and crop responses to water/nutrient applications. The difficulties in obtaining real data were reinforced by the specific objective of the contract that no funding should be provided for additional experimental work. This data supply problem was overcome by the utilisation of existing models (PT) to develop data sets that were representative of the regions being studied. These data sets gave values for yields of maize in relation to differing application levels of water and nutrient. The levels used with the model for water were derived through discussions with the SUA team in Tanzania. They stipulated the levels to be inputted based upon their intrinsic knowledge of the environmental conditions in Tanzania. The levels for nutrients were based on the standard application rates for additional nutrients as outlined by the SUA team.

With regard to qualitative data, scepticism can arise from the verbal feedback received from participants during the use of questionnaires and surveys. However by using a relatively large population for the surveys, the collated information could be verified and justified as being representative for the whole population. Also general observations carried out by extension officers in Maswa and WPLL ensured the reliability of the approach.

As already discussed at the onset of this research within Chapter Two, a major limitation to the data that has been collected is in reference to the nature of collection and hence interpretation of the data as well as the positionality and role of the researchers involved in the study. The data was collected and collated solely by the team out in Tanzania. The information was passed onto the team in Nottingham in an already manipulated format. The raw data was not provided, which in turn limited the level of interpretation and analysis that could be performed by the Nottingham team. We were reliant on the information provided by the team in Tanzania and their interpretations of the collected data and observational information.

4.4 Primary research results

Detailed below are the primary results from the surveys and investigations carried out in the two study regions.

The results are stated simply, and these are further expanded and expressed within the next chapter that highlights how the results have been applied to the development of the Tanzanian DSS.

4.4.1 Qualitative results

The objective of the qualitative research has been the establishment of greater understanding of the existing conditions and agricultural practices being performed in the study regions. This has helped to highlight problem areas and areas of improvement. It has also helped to instigate questions that could be tackled by the development of the DSS.

The majority of the information collected from these methods has been for the formulation of lists and tables. These have subsequently been analysed to formulate a database within Microsoft Access. Many of the tables have also highlighted characteristics of wealth and classification within the different communities studied.

Each of the four methods shall be discussed, highlighting their collection, delivery, purpose and output.

4.4.1.1 Questionnaires, Focus Groups and Surveys

Results from the baseline survey are summarized below for both Maswa district and WPLL. The results show the following elements of the current extent of rainwater harvesting, in the study area:

a) A substantial number of households (HHs) are already using RWH systems especially for crop production. For example, the macro-catchment RWH system that includes the excavated bunded basins (*majaluba*) for rice production is practiced by an estimated 28,000 HHs in Maswa District.

b) Rainwater harvesting is practised for crop production and for domestic water supply by more than 60% of the households. Rainwater harvesting for livestock water needs is practiced by less than 40% of the households.

c) *In-situ* RWH systems are predominant in the study areas. A percentage of households in Maswa and Same Districts also practice at least one type of macro-catchment system. Only about one quarter or fewer HHs practice macro-catchment systems with storage.

d) It is estimated that current farm sizes treated with RWH range from 0.6 to 1 ha per HH. This is small and there is scope for expansion of area under RWH per HH.

e) It is difficult to estimate the number of livestock benefiting from RWH. This is because the true numbers of livestock owned are rarely revealed. However, rough estimates show that more than 24,000, 6,000 and 4,000 livestock units are benefiting from RWH in Maswa, Mwanga and Same districts, respectively.

f) Most of those using macro-catchment RWH systems have adopted the technology since the 1990s. There has been a doubling in the adoption of most of the RWH techniques in the ten-year period between 1990 and 2000. Maswa district has seen the most rapid expansion in RWH especially in relation to excavated bunded basins (*majaluba*) for the production of paddy rice.

g) Maize yield in RWH systems is between 1.3 and 3.2 t/ha compared to the potential of 5 t/ha. The rice yields are currently 3.2 t/ha compared to a potential of 6 t/ha.

Much of the information obtained from the questionnaires and focus groups has brought about the production of a database that has been developed in Microsoft Access. The fields of interest for the database are those that were being investigated through the questionnaires and surveys, primarily focusing on what rainwater harvesting and nutrient management techniques are currently in place.

4.4.1.2 GIS

Figure 4.7 below illustrates one of the GIS maps that were developed during this research (Ludovic, 2003). It highlights the cropping practices as well as local infrastructure such as local roads and access to water resources.

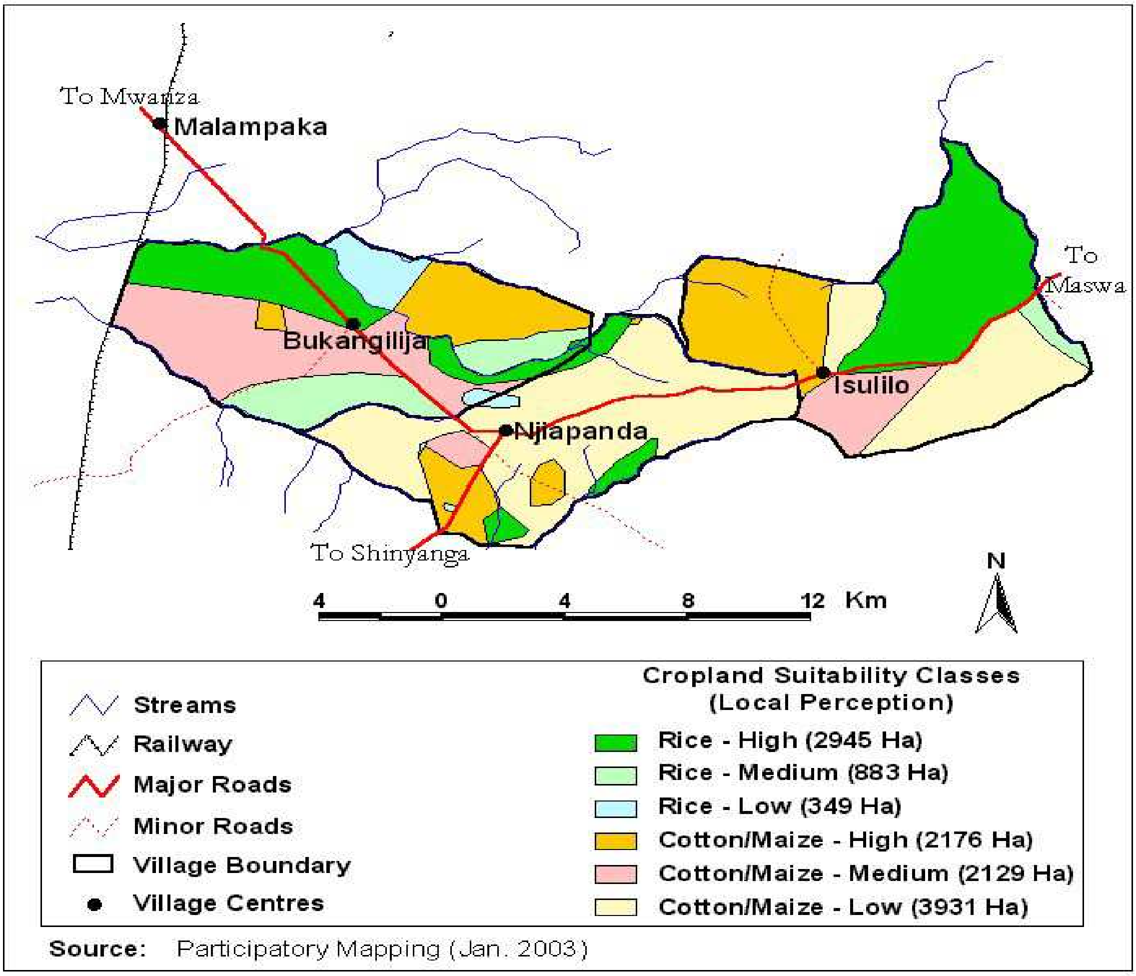


Figure 4.7: **GIS map highlighting local infrastructure.** (Ludovic, 2003)

These maps introduce a visual tool that can be incorporated into decision support systems or used as stand alone maps that can be used to highlight scenarios.

4.4.1.3 PRA (Participatory Rural Appraisal)

Table 4. below highlights one of these tables that were produced for the different groups of stakeholders, outlining the influence of the different criteria for wealth ranking.

	Groups		
Criteria	**Rich**	**Middle**	**Poor**
Housing	Built with bricks/block, roofed with iron sheets with glass windows Well furnished	Built with bricks and roofed with iron sheets Poorly finished Not well furnished	Built with poles mud and thatched with grass
Land	Not applicable	Not applicable	Not applicable
Livestock	Own more than 10 heads of cattle More than 15 goat	Less than 15 goat Less than 9 heads of cattle	Only chicken
Food security	Never experience hunger	Sufficient	Food insecure – can take single meal a day
Business enterprises	Run large shops and guest houses Own gypsum mine and engaged in gypsum trading	Engaged in petty business	Not engaged in business
Clothes:	Wear expensive clothes	Self sufficient	Poor clothing
Remittances	Not applicable	Not applicable	Not applicable
Farm implements	Either owns or can pay for tractor services in farm operations	Own/ use none	Own none
Access to social services	Afford costs of primary education and health service	Afford costs of primary education and health services	Cannot afford costs of primary education and health services
Access to farm inputs	Use farm inputs	Do not use modern farm inputs	Cannot afford farm inputs
Self-confidence	Self confident	Self confident Attend social gathering/ meetings	Not self confident Do not attend social gatherings
Begging	Do not beg	Do not beg	Always begging
Membership to local networks	Members of local networks Can lend small credit (up to 10,000 TAS)	Member of local networks Can borrow and lend small credit	Do not belong to any formal local network
Wage labour	Hire labour for farm operations	Occasionally hire labour for farm operations	Depend on casual work/usually sell labour to others
Proportion	**20%**	**70%**	**10%**

Table 4.14**: <u>Ranking criteria.</u>** Characteristics of wealth groups as perceived by elder male agro-pastoralists in Makanya village. (Information provided by Kajiru and Msangi, 2002)

Table 4.15 illustrates the response of a female agropastoralist in the Makanya village to the same questions/criteria as listed in Table 4.8. Differences can be observed. The criteria have subsequently been used for determining wealth classifications and to show how stakeholders' perceptions differ.

	Groups		
Criteria	**Rich**	**Middle**	**Poor**
Housing	Built with bricks/block, roofed with iron sheets with glass windows Well furnished.	Built with bricks and roofed with iron sheets Poorly finished Not well furnished	Poorly -made of poles, mud and thatched with grass
Land	Own more than 5 acres	Own 3-5 acres	Own 1-2 acres
Livestock	Own more than 5-30 heads of cattle More than 20 goats	Less than 6 goats Less than 4 heads of cattle	Own 1-5 goats 1-3 heads of cattle
Food security	Never experience hunger	Sufficient	Food insecure
Business enterprises	Run large shops, hotels and guest houses; Own gypsum mines and engaged in gypsum trading	Engaged in petty business	Not engaged in petty business
Clothes:	Wear expensive clothes	Self sufficient	Poor clothing
Farm implements	Hire tractors for farm operations	Use none	Use none
Access to social services	Afford costs of secondary education and health services	Afford costs of primary education and health services	Cannot afford cost of education and health services
Access to farm inputs	Use modern farm inputs	Do not use modern farm inputs	Cannot afford costs of farm inputs
Self-confidence	Self confident	Self confident Attend social gathering/ meetings	Not self confident Do not attend social gatherings
Begging	Do not beg	Do not beg	Always begging
Membership to local networks	Member to networks Can lend small credit (up to 10,000 TAS)	Member of local networks Can borrow and lend small credit (1000-10000)	Not member of social networks
Wage labour	Hire labour for farm operations	Occasionally hire labour for farm operations	Live on casual work/sell labour to others
Proportion	**20%**	**50%**	**30%**

Table 4.15**: Ranking criteria.** Characteristics of wealth groups as perceived by elder female agro-pastoralists in Makanya village. (Information provided by Kajiru and Msangi, 2002)

Many tables were developed for the different stakeholders within the villages. It was necessary to condense and distil out the most important information from these tables to formulate a single table (Table 4.16) that gives details of the criteria used by local people for wealth ranking and details that can be used when determining which level the stakeholder perceives themselves to fall under.

	Rich	Middle	Poor
Housing	Built with bricks, roofed with iron sheets with glass windows. Well furnished.	Built with bricks and roofed with iron sheets Poorly finished Not well furnished	Built with poles mud and thatched with grass
Livestock	Own more than 10 heads of cattle, more than 15 goats	Less than 15 goats Less than 9 heads of cattle	Only chicken
Food security	Never experience hunger	Sufficient	Food insecure - take single meal a day
Business enterprises	E.G. run large shops and guest houses. Own gypsum mine and engaged in gypsum trading	Engaged in petty business	Not engaged in business
Clothes:	Wear expensive clothes	Self sufficient	Poor clothing
Farm implements	Either own or can pay for tractor services in farm operations	Own/ use none	Own none
Access to social services	Afford costs of primary education and health service	Afford costs of primary education and health services	Cannot afford costs of primary education and health services
Access to farm inputs	Use farm inputs	Do not use modern farm inputs	Cannot afford farm inputs
Self-confidence	Self confident	Self confident Attend social gathering/ meetings	Not self confident Do not attend social gatherings
Begging	Do not beg	Do not beg	Always begging
Membership to local networks	Member of local networks Can lend small credit (up to 10,000 TAS)	Member of local networks Can borrow and lend small credit	Do not belong to any formal local network
Wage labour	Hire labour for farm operations	Occasionally hire labour for farm operations	Depend on casual work/usually sell labour to others
Spouse/marriage	Rich spouse	Often not married	Often not married
Ability to pay bride price	No problems	Can afford with few difficulties	Sons marry late or remain single due to lack of bride price Daughters get married as teenagers (< 15 year)

Table 4.16: Socio-Economic factors used to determine the level of wealth of farmers. (Information provided by Kajiru and Msangi, 2002)

These criteria can be used by the extension officers when determining the wealth classification of individuals, which is subsequently fed into the DSS.

The above criteria for identifying the poor included a combination of material and non- material assets. The reasons why these criteria were used are described below alongside additional observational information that was recorded by the SUA team while collating the information.

Material criteria for wealth determination

Housing: The quality of a house where one lives in was an important factor for determining wealth status. However, in pastoralist groups, living in a standard house was not perceived as important. Most pastoralists live in very poor houses, but they might own modern rental houses in nearby townships. Quality of houses varied from poor i.e. those made up of mud and poles and thatched with grass commonly found in WPLL and those made of poles and mud only common in Maswa. There were moderately good houses made of poles and mud, or unburned bricks and roofed with iron sheets, these were common in both WPLL and Maswa. Modern houses mentioned were those made of bricks or blocks and roofed with iron sheets. These are well plastered, sometimes with glass windows and fully furnished.

Livestock: Livestock is an important factor for determining wealth status of an individual in both target areas. Livestock is easily converted into other forms of assets like cash, food and farm implements. The most referred one were cattle. Cattle are a traditional symbol for wealth in Sukuma, Maasai and Pare communities. In all cases, livestock play important social functions as paying bride price and source of secondary products (eg milk, meat), which are sources of nutrients and income to households. However, the number of heads one should own for being recognised as well-off varied with specific groups and geographical areas. Pastoralists in Mwembe village consider individuals with more than 10 heads of cattle as rich while poor person posses none. In Makanya and Bukangilija villages rich pastoralists own more than 100 heads of cattle and poor possess none. For agropastoralists in Makanya a person is considered rich when he/she possesses not less than 10 heads of cattle. Youth in Mwembe reported that for them a rich person should own at least 2 heads of dairy cattle or 7 heads of indigenous cattle. Female household heads in Isulilo (in Maswa district) regarded individuals with more than 10 heads of cattle as rich.

Land: Ownership of land for different enterprises was an important factor in wealth ranking. Land could be used for crop production and grazing. Both quantity and quality of land are important indicators of wealth status. Quantity and quality of land for crop enterprises varied with proximity to water source. For example in Mwembe village in the WPLL having a farm plot near the stream qualifies one as wealthy.

Amount of land needed by different socio-economic groups to classify one as rich or poor varied substantially. Pastoralists in both WPLL and Maswa classified a person with a minimum of 50 acres of grazing land as rich. On the other hand, farmers regarded a person with 5 acres of cropland as rich in WPLL compared to 10 acres for Maswa district.

Food security: Food self-sufficiency emerged to be an important factor for wealth ranking in all social-economic groups consulted. Those who were considered well-off had plenty of food (stock lasting for one year or more) while the poor had stock that could last for 1 - 4 months after harvest. The amount of food was found positively related with land/farm holdings that an individual own or manage.

Business enterprises: Engagement in business enterprises plays a substantial role in improving economic well being. It supplements income from agricultural and livestock production activities. Businesses mentioned varied from mining and trading of gypsum and small-scale food processing like foods vending locally known as *mama nitilie* in WPLL. In Maswa district major business enterprises were grain milling and grain trading and *mama nitilie* as well.

Clothes: Ability to afford cost of clothes appeared to be important in determining wealth status. Poor people wear poor clothes and sometimes their children could go naked while the well-off people afford expensive clothes.

Remittances: In some cases, for example women agropastoralists in Mwembe village, it was pointed out that remittance was an important factor to determine economic well being of women. This could be sought from sons and daughters who have good jobs.

Farm implements: In Maswa district implements like ox carts, ox ploughs and ox weeders are important in classifying one into a wealthy status. Holders of these implements could manage relatively large farms and do farm operations timely thus realising higher yields compared to their counterparts. Sometimes these implements could be leased/ rented out for money directly.

Non- material criteria for determining wealth status

Access to social services: Ability to afford costs associated with social services like education and health services signified individuals wealth status. Wealthier people could pay for primary education and medical services for their families. Children from poor families do not attend school for some periods of the year due to lack of either fees, or other associated costs. The poor sometimes depend on traditional healers, as they do not afford for medical services.

Access to farm inputs: The ability to afford farm input indicates whether one is economically poor or well-off.

Marital Status: Women in Mwembe village in WPLL mentioned that being married was important for one's economic well being. This is especially the case when a husband comes from a rich family and is responsible for family well being. Men, however did not concur with this conclusion.

Self-confidence: This was perceived as an important factor and was highly linked to leadership capacity. Individuals in middle wealth group were considered to be good in this respect and are the ones who take leadership positions more frequently. Self-confidence gives individuals power to make their own decisions or influence decisions of others.

Begging: Dependence on food aid and begging were tendencies that indicated one's level of poverty. However, there are differences in things normally begged for by poor men and women. Poor women tend to beg for food and clothes while men beg for cash and brew.

Membership to local networks: This was found to be important in both target areas and to most of the socio-economic groups. The networks composed of neighbours, families and friends. Benefits of being a member to these networks included assistance in a form of labour, gifts and credit.

Wage labour: Engagement in casual works (*vibarua*) determined one's wealth status. Casual labourers do not have enough time to work in their own fields and found themselves getting little yield every season. According to farmers from Bukangilija village, some poor men do get credit in a form of food and money from rich people well in advance of the rain season with an agreement that they would pay by casual works. Sometimes poor people could easily lose their farms to the rich upon failure to pay back the credit.

Ability to pay bride price: In both target areas, ability to pay for bride price indicates individual wealth status. Male youth from well-off families get married in time where as those from poor families do get married late or sometimes remained unmarried. Close to this, women in Mwembe (in WPLL) reported that daughters from poor families often get married at teen age (below 15 years).

Using these criteria the communities were stratified into three wealth groups, the rich group, the middle group and the poor. These are also the criteria that are used within the DSS.

4.4.2 Quantitative results

The results obtained from the quantitative studies consist of crop yields for maize at different levels of nutrient application, and information related to climatic and topographic information obtained from utilising existing models. These models have also helped to provide representative yield information for the two crops – rice and maize – that have subsequently been manipulated to help give rise to the relationships used within the DSS.

The actual collection of physical data in the field by the extension officers was compromised by time, and lack of funding for extra field experiments. Hence alternative sources of numerical data were utilised – these predominately being the use of the Parched-Thirst model and existing literature that details resource relationships for the crops of interest.

Numerical data were collected, although only some of these have been used within the development of the DSS. The data that have been collected and used shall be further detailed within the 'Application of Information and Development of the DSS' chapter (Chapter 5).

4.5 Further points

The results obtained for both the qualitative and quantitative studies have helped bring about the development of further computer systems and applications. These include:

- The development of the DSS
- The development of a 'quick reference' database of management decisions
- The development of ranking and criteria spreadsheets that can be utilised for decision-making processes.

These systems shall be discussed and detailed in the following chapter.

Chapter Five

APPLICATION OF INFORMATION AND DEVELOPMENT OF THE TANZANIAN DSS

The objective of this chapter is to illustrate the application of the derived information detailed in chapters two, three and four, and how it has been applied for the production of the Tanzanian DSS.

5.0 Theoretical Background – System Overview

Simply, a DSS is a system under the control of one or more decision makers. They assist in the activity of decision-making by providing an organised set of tools intended to impose structure on portions of the decision-making situation. The effectiveness of the decision outcome is often improved as a consequence of this improved structure to decision-making (Guariso, 1989; Galitz, 1997; Burckhard, 1999; Deitel, 1999; Marakas, 2002).

The aim of the Tanzanian DSS is to complement the intrinsic knowledge of the Tanzanian farmers to help enhance or maintain the sustainability of their livelihoods. Through participatory analysis, the DSS should also be used as a tool to question existing practices and identify new approaches.

The development of the Tanzanian DSS comprised two phases. Phase one focused on developing mathematical relationships by utilising data and manipulating this within Microsoft Excel. Phase two integrated the derived relationships into the Delphi designed model.

The data input requirements involve the following parameters (Table 5.1), each of which can be utilised and manipulated within the MS Excel spreadsheet/model. The PT model and participatory analysis were used to generate much of this data (Moulin 1994; Matthews, 2002). The data requirements were discussed with the team in Tanzania to ensure that all requirements were covered.

Parameter	Units	Derived by	Notes
Slope	%	PT model and direct calculation/observation	Influences the movement of resources
Soil type	Local terms	Participatory analysis and chemical analysis of soil components	Influences the capture and release of nutrients and management options
Land area and cropping area	ha	Direct measurement and questioning of farmers	Size of farms
Crop	-	Observation and questioning	Focus is on maize and rice
Rainfall, runoff, runon, irrigation, total water	mm	Manipulation of PT model data and the link with rainfall data	All issues related to current water conditions
Bought water	m^3	Participatory analysis	Influenced by the status and wealth of the farmer
Cost of bought water	TAS	Website details	Influenced by volume acquired
Yield response to water	Tonnes ha^{-1}	PT model generated yield data	Manipulated in Excel
Nutrient application	kg ha^{-1}	Participatory analysis and questioning	Levels of nutrients added
Nutrient uptake	kg N ha^{-1}	Derived from literature	Only a proportion of nutrient will be used by the crop
Yield response to nutrient	kg ha^{-1}	Relationship obtained from Loomis *et al* (1999).	Generic relationship has been implemented
Linking responses	Tonnes ha^{-1}	Law of the minimum	Such that the minimum yield is the one used for further calculations. Link between nutrients and water
Yield conversion	kg	Multiplication to convert tonnes into kg	For compliance with the rest of the model, units need to be uniform
Value of a bag of grain	TAS	Fixed cost stated by Tanzanian economists	Needed for determining the total income from the generated yield
Number of bags	Unit	Derived from the total yield and the weight of a single bag	Needed for calculating the value for the crop
Total value	TAS	Multiplication of value of a bag by the total number of bags	Income generated from the yield of crop
Land preparation, input farm operation costs	TAS	Tables provided by Tanzanian partners	Economic variables

Table 5.1**: <u>Input Data Requirements.</u>** Parameters that are utilised for model development.

The above input data requirements can be loosely grouped into the following sections for further description:

- Topography and land characteristics
- Data related to water requirements
- Data related to nutrient requirements
- Costs

Each of these shall now be discussed in relation to their importance for the development of the Tanzanian DSS and with regard to comments from the teams in Nottingham and Tanzania.

Topography and Land Characteristics

Topographical information such as land relief can be inputted within the PT model. Hence it will be utilised within the generation of the data sets for the development of the Tanzanian model. Slope characteristics were derived from maps and through discussions with partners in Tanzania. Geophrey Kajiru provided the team in Nottingham with soil profile information as detailed in chapter 2. This information has helped in understanding the current land profile of the study regions in Tanzania. Land areas were obtained from the extension officers in the field who carried out observational surveys of the farming land. Information was tabulated and supplied to the team in Nottingham. Refer to Appendix 6 for examples of these data sets and reports that were utilised for the development of the Tanzanian DSS.

Data related to water requirements

Water is a fundamental resource being utilised within the Tanzanian model, therefore extensive data was required on its uses and application in the field, alongside its affects of crop growth. Limited field experiments were carried out by the team in Tanzania to look at the effects of varying levels of water on crop growth. Therefore the PT model was used to simulate water (rainfall) events for a 30 year period. Rainfall was the most important factor. Within the PT model, levels of water for the events of runoff and runon are also stipulated, these give rise to information about additional water that is moving into a field, as well as detailing any potential water losses through water movement into adjacent fields. The levels of rainfall simulated were tabulated (refer to Appendix 6) and expressed to the team in Tanzania, who subsequently confirmed the data as being suitable for further manipulation and use within the development of the Tanzanian DSS. PT also generates data on the influence of water on the yield of rice or maize. All outputs derived from the PT model were tabulated and Emailed to the team in Tanzania for cross-reference checking before they were used within the model development.

Data related to nutrient requirements

As with water requirements, the nutrient requirements were derived and tested through the use of the PT model. These were subsequently tabulated and checked with the team in Tanzania to ensure their feasibility for use within the Tanzanian DSS. Areas of interest included the application of inorganic nutrients such as chemical fertilisers, as well as the application of organic fertilisers like manure. From discussions with Abeid Msangi (a member of the Tanzanian research team) it was concluded that the important nutrient application was that of manure as it is more freely available to the farmers in the field. For the development of the Tanzanian DSS, Nitrogen was the main nutrient focused on. Through discussions with the team in Tanzania, this nutrient was seen as the most influential on the growth of crops and a prominent component of manure produced by livestock.

Costs

An element of the Tanzanian DSS is that of cost analysis and understanding potential cost benefits of applying certain management strategies related to water and nutrients. Therefore it was essential to have an understanding of the different costs of nutrients and additional water sources, as these will need to feed into the model. Appendix 6 details some of these costs. There are various land preparation and operational costs that were identified by the team in Tanzania. These were expressed to the team in Nottingham as a monetary value (TAS).

Examples of these data sources and types as generated by the PT model, or provided by the team in Tanzania can be viewed on the CD-Rom titled ‘Documentation’, within Appendix 6.

The model optimises the cropping area, bought water and nutrient applied to give the best-cost balance, as well as highlighting the best method for allocating the resource. The desired result from the optimisation procedure is to give the farmer a preferred level of nutrient application and a level for additional water application based on the inputs that they specify – such as their land area, status, wealth etc. This will of course be limited by the costs that they can afford.

The DSS has the capabilities to take data from the field related to crops, soils, water levels, nutrient applications and costs and apply an optimisation procedure to the adjustable variables to obtain an optimal management approach. Further encyclopaedic information and options can be derived from the developed databases (Boote *et al*, 1996; Benbi, 2003).

5.1 Phase One – DSS Development

To facilitate the development of the DSS, various computer software packages were utilised (Fielding, 1995).

1. Delphi – a programming language used for the development of the front-end of the system.
2. Microsoft Excel – used to develop the relationships. Spreadsheets are implemented to carry out the optimisation procedures.
3. Microsoft Access – used for the development of databases that houses the encyclopaedic information and details of the existing conditions observed.
4. PT Model – used for the generation of data sets for building relationships.

For the development of the DSS, various attributes had to be considered. The majority of those relating to the study area have been outlined within Chapter Two. Attributes include, having an understanding of the topographic information surrounding the study area as well as the existing water and nutrient conditions. Further considerations are given to the cost of resources and the application/understanding of CPR and their management.

The desired topographic information is concerned with determining the existing characteristics related to a farmer in Tanzania. Information has been derived through visual observations (e.g. photographs) and the implementation of questionnaires at a field/community level (Evans, 1993). The two catchments for the model were Maswa and the WPLL.

These different catchments have differing characteristics related to soil types and crops grown, as well as the available land given over to agriculture. GIS mapping can help to illustrate these differences.

The crops investigated were rice and maize. These crops provide examples of the physiology and attributes of C3 and C4 photosynthetic systems respectively. In principle, an understanding of their relationships in the field can be applied to different C3 and C4 crops being grown under similar conditions. Maize and rice are just two crops that are being grown in Tanzania. In addition to other staple and cash crops, vegetables and flowers are also grown.

For modelling purposes, the productivity of the crop is estimated on a per hectare basis. This is subsequently converted to the local units of acres using a conversion factor of 0.4.

The purpose of topographic information within the model is to highlight factors that influence the potential agricultural practices and options. For example soil type will influence the flow of water depending on the soil characteristics. The relief of the land will influence the potential movement of water through the system.

The initial development of relationships between crop productivity and water/nutrient application were produced in Microsoft Excel. The relationship for the total available water was defined by summing all the different water sources (irrigation, rainfall and runon) and subtracting the runoff value. The outputs used were collected by running the PT model for a 30-year period.

The model calculates

- Total volume of water available for agricultural purposes
- How much additional water can be added to the system

A simple arithmetic equation is used for determining the total volume of water available. (Steduto, 1996; Overman *et al*, 2002; Kijne *et al,* 200

Total water = Irrigation + Rainfall + Runon - Runoff

Irrigation is the volume of additional water.
Rainfall is the volume of water that falls as rain during a given period (year).
Runon is the volume of water that is additional to the system following movement from other areas – surface runoff from one area to another.
Runoff is the volume of water that is lost from a given area.

By running the PT model for a 30 year period, outputs were collected for the purpose of relationship building (Wyseure *et al*, unpublished). The information obtained was confirmed as representative of the study regions (Tumbo, Personal Communication, 2004). Initial trends were developed within Microsoft Excel (Walkenback, 2001) and were subsequently used for the development of the Tanzanian model.

The focus of the nutrient information was on the effects of various forms of nitrogen application. The following components are considered:

a) Source. i.e. total applied through either manure or inorganic fertiliser
b) Uptake. i.e. nitrogen taken up by the crop
c) Response. i.e. crop yield response to nitrogen (kg N ha^{-1})

The total available nitrogen depends upon what proportions of nitrogen are present in the soil and those that are added. The proportions used within this model were obtained from Kourik (1986). The nitrogen applied is simply the sum of the two components – the nitrogen present and the additional nitrogen.

Additional nitrogen can come from either inorganic (chemical fertilisers) or organic (manure) sources. The majority of farmers in Maswa and the WPLL utilise manure as this is often readily available to them (Cooke, 1967; Fageria *et al*, 1997).

The proportion of nitrogen in the fertility treatment is governed by an application rate derived from Kourik (1986). The value for organic fertiliser (manure) is assumed to be 2.15% and for inorganic fertiliser it is assumed to be 30% (Norman *et al*, 1995). The level of nitrogen in the applied nutrient therefore is assumed to equal

Nitrogen applied = (0.0215*Volume of manure) + (0.3*volume of inorganic fertiliser) (Kg N ha^{-1})

Only a proportion of the nutrient applied will be taken up by plants and used for biomass production. The nitrogen uptake is affected by the biomass of the crop (Loomis *et al*, 1992 and 1998).

Two other areas of nutrient management introduced within the DSS related to

a) The volume of manure produced by livestock
b) The volume of nutrient lost from the field following harvesting.

These calculations will allow estimates of the nutrient application needed to replace any losses.

Water and nutrients are the two important aspects of the model. The link between the two and their combined and independent effects on yield need to be included within the model.

For the Tanzanian model the 'Law of the Minimum' (Bradley and Crout, 1994) is being utilised. This approach has been used before to derive relationships within the initial PT model. The law simply takes the two components and assigns the value for the link between variables to be the component with the lowest value.

With regard to costs, the model is designed to calculate optimal returns such that profits are maximised and input costs minimised. As with many agricultural systems, there are costs involved in production and maintenance of the system. Profits arise from the success of crop performance, costs of inputs and the market price for the crop.

Many of these costs and variables are transaction costs and within the optimisation procedure may be discounted from the equation. This will depend upon the status of the farmer.

The concept of CPR is a fundamental aspect of the Tanzanian DSS. By scaling up the Tanzanian DSS from a single field to multiple fields, an assessment of the costs and benefits of RWH CPR management systems can be made (Ballabh *et al,* 2002). Essentially, the DSS will predict the potential benefits of collaborating in CPR management of RWH systems (in terms of additional income and yield at the catchment level) as well as the financial and transaction costs of such actions. These costs and benefits will be provided by the model in a format that can be discussed between local extension officers and community leaders.

The ultimate decision whether to actually adopt CPR management or improve individual RWH systems is not one that the DSS can provide. This will depend very much on the nature and interactions of the community groups that make up the catchment: something that cannot realistically be modelled. Instead, the DSS will be used to help instigate questioning amongst farmers and extension officers to help determine their suitability for CPR management techniques. Ostrom's criteria (Ostrom, 1999) as described in Chapter Two form the basis of this interactive questioning.

The inclusion of CPR in the DSS is intended to facilitate decision-making at the community level regarding the costs and benefits of adopting village or catchment level RWH CPR.

Alongside the development of the Tanzanian DSS, various databases have also been produced. A simple relational database has been set up within MS Access. The purpose behind the database is to give the extension officer a quick reference point with regard to the farmer's current farming conditions.

Database fields have been assigned within Microsoft Access, particularly in relation to observational data. The data inputted within the database under the following fields was collected during the application of the social sciences questionnaire that can be viewed within Appendix 6 (Reports section). The work of Geophrey Kajiru and Abeid Msangi contributed to the collection of this information. The data was tabulated and passed onto the team in Nottingham for the development of the simple relational database that has been set up in MS Access. The database fields derived from the information provided by the team in Tanzania are as follows:

- Area – this is the district area, that of Maswa or WPLL.
- Position – the position relates to the position of the farm in the catchment. Three positions are possible – lower, middle or upper catchment. This can be determined by observation.
- RWH system – this is in relation to any existing RWH techniques that might already be in place within the study area or being performed on the farm in question.
- Runoff – different levels of runoff have been recorded through observation and discussion with farmers in the field. Within the database these are specified as ‘adequate’ or ‘inadequate’, and relate to the additional water that a farm can receive following a rainfall event.
- Cropping system – the cropping system is the type of crop being grown, whether it is just a single crop or a combination of crops.
- Farmer Category – through PRA techniques the classification of farmers has been derived. This section in the database details whether a farmer classifies themselves as rich or poor or within the middle range.

Links are present between these fields and it is these links that help to give rise to the searches that can take place within the database. The subsequent output from the searches in the database detail the agricultural management options available to the farmer in question based on the inputs provided by them. This information within the database was derived from research in the field, hence it can be stated that its reliability of outputting feasible results for the farmers in Tanzania is high, as the information has been supplied by Tanzanian farmers. The database has also been discussed with the team in Tanzania and its use and outputs have been concluded as being feasible.

5.2 Data and variables

The data and information used for the building of the model and DSS are from three sources:

1. Participatory questioning of the communities in the catchment areas
2. Field data/experiments
3. Parched-Thirst (PT) model manipulation

The DSS components that make up the databases and mathematical relationships were

- Location considerations – catchment, village, position
- Slope
- Soil type
- Land area and potential cropping area
- Variable and fixed costs
- Total water. Derived from irrigation, rainfall, runon and runoff
- Nutrient applications – manure and fertiliser

The reasons why these components were chosen for the development of the mathematical relationships and the DSS are as follows.

Location Considerations

Two catchment areas were chosen for this study – Maswa and the WPLL. These were pre-determined by the team in Tanzania as much research into soil and water management had previously been performed in these areas. It is important for the extension officers to know about the location that they will be using the DSS for as this may influence the further inputs that are made to the system. The other influencing inputs are related to the topography of the area and existing conditions in relation to water and nutrient management. These may differ between locations. For the collection of data different villages were investigated within the main catchment areas and results related to existing management techniques recorded. This differentiation between villages has been useful in building the agricultural management database system in MS Access. The knowledge related to the different catchments and villages was extrapolated to the team in Nottingham via reports that were compiled by the team in Tanzania. Examples of these reports related to Maswa and WPLL can be viewed in Appendix 6 under the reports section.

Slope

Details of land relief (slope %) are important for determining the rate of runoff and runon following a rainfall event. It will influence the level of additional water that a field may capture. The measurements of slope were carried out by the scientist in Tanzania. For the development of the DSS various slope percentages were inputted to see the sorts of outputs that were produced. These outputs were derived from the mathematical relationships that the development Team in Nottingham had created. All result from these tests were tabulated and discussed with the team in Tanzania to ensure the feasibility of the outcomes and to ensure the parameter of 'slope' was functioning correctly within the model.

Soil Type

The soil type on the farm will influence the movement of water and nutrients and the plants ability to take up the available resources. Knowledge of soil types will also affect the types of crops that can be grown. Some soils will be more suitable for some crops while others may not be. Extensive research into the types of soils present in the study regions has been carried out within the Soil and Water Management research being performed at Sokoine University of Agriculture. Table 2.6 and 2.7 illustrate clearly the types of soils that are present in Tanzania and highlight the crops that can be grown. This information was compiled by Geophrey Kajiru. The farmers in Tanzania have their own terms for the types of soil that is present on their farms and they are very knowledgeable about the management of the soil type in question. Soil type is an element that is included within the management database that has been developed during this research.

Land area and potential cropping area

The extension officer working with the farmers in the field will have to record the land area of the farm(s) for inputting within the DSS. When taking this measurement they will need to be aware that not all of the land area may be suitable for cropping purposes. Also the farmer in question may use some of the land for other purposes such as for livestock rearing. Discussions will have to be held in order to determine the land area that can be inputted within the DSS and utilised by the derived mathematical equations. The land area component is particularly important to the DSS as one of the outputs from the model is an understanding of the optimal use of the land area in relation to which crops to grow. Based on the inputted land area, this will be divided between the crops (rice and maize) and the area of land that should be given over to the growth of the crops stipulated. This output is only an estimate and should be discussed further with the farmers to ensure its feasibility. For the development of the DSS and mathematical relationships, farm areas (land areas) were supplied by the team in Tanzania based on real observations in the field.

Variable and fixed costs

Another element of the developed Tanzanian DSS is to be able to extrapolate the monetary value of the crops being grown. This function of the model introduces an element of economics to the system. Various costs have to be considered. There are costs associated to land management and farming practices carried out. These will depend on the additional resources that are available to the farmers. Additional costs may rise from the use of fertilisers and additional labour. These costs need to be subtracted from any profit that is made from the production of crops. Knowledge of the market value for rice and maize is required for determining the potential monetary outcome of the crop yield. This is likely to change, hence within the DSS this value needs to be able to be altered if necessary. The costs associated with land preparation and machinery have been determined through discussions with the team in Tanzania. These can be viewed within Appendix 6 within the ‘Data’ folder. Various costs were considered within phase one of DSS development including the costs of additional water, land preparation, labour, farm implements etc. Within the final DSS system labour is seen as the most influential factor on the cost of management techniques. The ability to afford additional labour to help manage ones farm is an indicator of wealth status and will also affect the productivity of ones farm. Costs such as farm implements are utilised within the understanding of wealth classifications and the application of a CPR regime. The DSS allows the extension to input values for the costs, these are free text fields.

Total water

Within phase one of DSS development total water was derived from rainfall, runoff, runon, irrigation and any additional bought water. Water is accessed from various sources. However its availability for different farmers varies. Therefore it is important for the extension officers to work closely with the farmers when determining the level of water that can be inputted within the DSS. Rainfall data events were derived by using the PT model that contained information for 30 years of rainfall events in the study regions. Before this data was used for the relationship building it was discussed with the team in Tanzania to ensure its suitability. The reason why the data was generated using the PT model was because no additional rainfall records or data was available for relationship development. Siza Tumbo from the Tanzanian team confirmed that the use of PT was viable as the system had been developed using data from the Tanzanian DSS study regions in the first place, hence the data was transferable. The total water available for crop production is one of the fundamental aspects of the Tanzanian DSS as it has been developed to look at water management regimes and the application of RWH techniques.

Nutrient application

Within phase one of model development both inorganic and organic nutrient application was looked into. Inorganic nutrients include the application of chemical fertilisers, while organic treatments primarily focus on the application of manure. These applications can be viewed within Appendix 6 within the folder called 'Data' and the file that details phase one model development. From research and discussion with the development team in Tanzania (Geophrey Kajiru, Omari Mzirai and Henry Mahoo) it became apparent that the most important source of nutrients for the farmers was the application of manure. For farmers with livestock, manure is readily available. However it can also be sold, hence bringing in additional income for those with livestock, and therefore can be used by farmers without livestock. The important component found within manure was the level of nitrogen. Relationships for this component were derived from the literature (Kourik, 1986; Loomis *et al.*, 1999) and subsequently built into the model. At this stage of DSS development the only nutrient looked into was that of nitrogen. Future developments of the system could consider other chemical components of manure such as phosphorus and potassium. Nutrient application influences the growth and productivity of the crops. Alongside water, it is a fundamental resource that has been considered and incorporated within the development of the Tanzanian DSS.

5.3 Relationship Testing

The above information gives details of the initial relationships that were built for the development of the Tanzanian DSS. These relationships have subsequently been tested and adapted using alternative sources such as literature.

Regression analyses were carried out on the data produced by the PT model and the data generated by the Excel generated DSS. Particular focus has been upon the relationships used for yield predictions.

Figure 5.1 demonstrates the reliability of the predicted yields obtained from the model and those generated within the PT model.

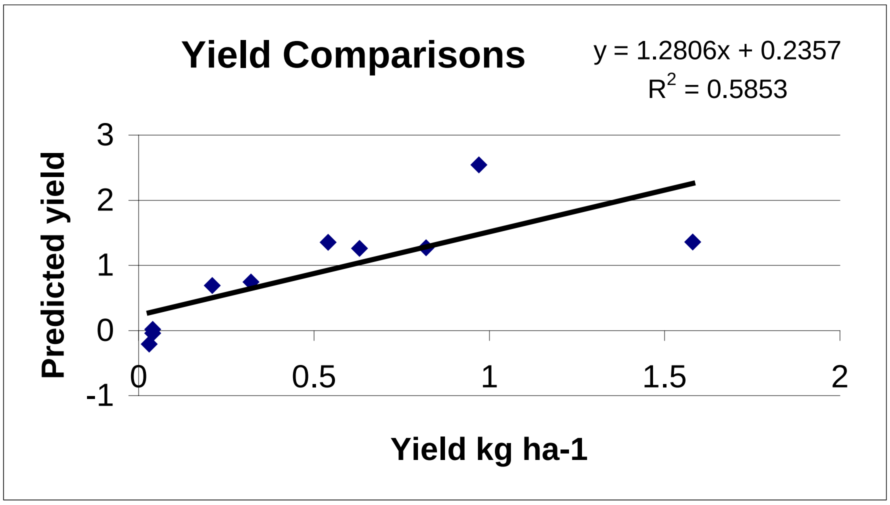


Figure 5.1**: <u>Comparative Study.</u>** Comparison between predicted (yield from the PT model) and generated (yield from the derived relationships) yields for maize.

The standard error generated for this data is 0.4 with respect to the differences between yield values. Genstat – a statistical analysis computer program - was used for the analysis of the data (Patel *et al*, 2001; Stern, 2004).

Chi squared analysis of the observed and predicted data values for yields can also be applied. The results from the Chi squared test state that observing a Chi squared value with 8 degrees of freedom greater in value than 8.46 is approximately 5% (Bailey, 2000; Stern, 2004).

The high standard error can be accounted for by the limited number of sample points. To help improve this relationship further data points are needed. Also the comparison between field data and predicted yields needs to be performed. It must be noted that this research is limited as comparisons between the model data and real field data have not been carried out, as field data were not available.

5.4 Optimisation Routines

A major attribute of the DSS is to be able to give the farmer the optimal combination (solution) of resource inputs that gives the most suitable management output for them. This optimisation procedure can be applied to the model and solutions derived. (Matthews *et al*, 2002)

Some of these variables can also be optimised and it is possible to look at the best combinations of these variables for specific outputs.

The variables that can be optimised include

- Cropping area
- Bought water
- Nutrient application

Three outcomes are possible

1. Greater utilisation of water resources
2. Greater utilisation of nutrient resources
3. Combination of both resources

The application of an optimisation procedure to the model has been via the utilisation of ‘Solver’ – a mathematical tool – within MS Excel.

Various constraints to the developed spreadsheet have been applied for the optimisation procedure. Constraints are restrictions that occur on the combination of strategies that can be selected. These constraints help ensure the solution is realistic, logical and achievable. Constraints specify a minimum, maximum or exact level of some factor in the solution. Constraints are wide ranging and include the following:

1. Cropping area has to be less than or equal to the land area
2. Cropping area has to be greater than or equal to zero
3. Volume of bought water cannot exceed the potential stored water
4. Bought water is greater than or equal to zero
5. Applied nutrient (manure) is greater than or equal to zero

Without these constraints negative values may influence the desired outcomes from the model.

On running the optimisation, the adjustable parameters are altered to give rise to the optimal solution. This solution can be recorded and the information portrayed back to the farmers in the context of management approaches for reaching this optimal solution.

The following section demonstrates the next stages for the development of the DSS as well as illustrating the front-end and final product produced.

5.5 Phase Two - The Tanzania Farm Model

5.5.1 Introduction

The Tanzania Farm model has been developed as a support system to estimate the benefits of considering a CPR management plan for farms located in two regions of Tanzania.

The model is divided into five sub-models (Figure 5.2):

1) **Labour sub-model** estimates the labour required by the farm (in terms of person days) to undertake and simulate management. In addition, the cost of employing this labour is also calculated.

2) **Crop sub-model** is the core of the Tanzania Farm model. Firstly, it estimates the crop yield (t ha^{-1}) as a function of available Nitrogen (kg ha^{-1}) and water (mm). Secondly, it calculates the harvest value (TAS) based on the estimated crop yield. Two crop sub-models are implemented in the software, one for each crop considered, i.e. maize and rice.

3) **Water available sub-model** estimates the amount of water available to crops. This is a function of rainfall (mm), water lost due to slope (runoff), water which flows into the field from the surrounding areas (runon) and if a CPR management plan is implemented, the available water is also a function of the volume of water (m^3) that is imported from the common pool resource.

4) **Common Pool Resources Access sub-model** is the innovative aspect of the Tanzania Farm model as it allows a consideration of the effects of a CPR approach in the farm management plan in term of profit (TAS). In the present model version the only resource considered to be shared among the community is water. CPR management is considered at the community level.

5) **Total Profit sub-model** provides the model final output, which is the estimation of the farm profit (TAS) that is a function of the optimised parameters such as crop and rain water harvest area (ha), nitrogen applied (kg ha^{-1}) and volume of water (m^3) extracted from the common reservoir.

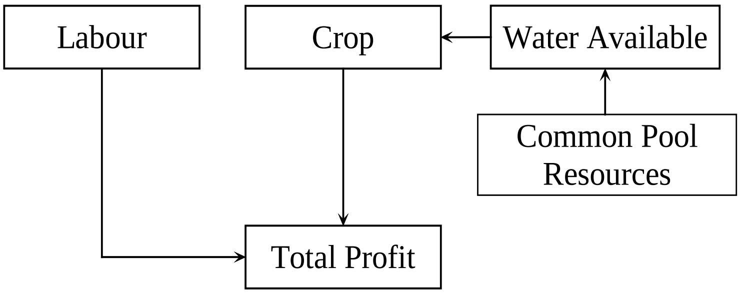


Figure 5.2. **Tanzanian Farm sub models**. The Tanzania Farm model is divided into five sub-models.

5.5.2 Model description

Labour sub-model

The estimation of the labour required to implement the proposed management plan is performed considering the labour cost on the crops management, nitrogen application and the management of the common pool resources (Equation 1).

$$Labour = AreaLabour + Ntotal * NLabour + CPR_V * CPR_L \quad (1)$$

$$AreaLabour = \left(RWH_A * RWH_L + \sum_{i=1}^{n} CropA_i * CropL_i \right) \quad (2)$$

where

Ntotal is the total nitrogen (kg) available for use on the farm.

Nlabour is the labour required to apply a kg of nitrogen and it is a model input.

CPR_V is an optimised parameter which indicates the volume of water (m^3) that is imported into the farm from the community reservoir.

CPR_L is an input parameter, which defines the labour required for the CPR management plan.

RWH_A is the farm area that is used for rainwater harvest and it is an optimised parameter.

RWH_L is a model input, which indicates the labour necessary for the management of rainwater harvesting.

CropA is the optimised area for the considered crop.

CropL is an input parameter that indicates the amount of labour required for the cultivation of the considered crop.

n is the total number of crops.

Costs associated with the labour required by the farm are estimated by multiplying the number of workers (Labour) and the cost of a single worker ($Labour_{value}$), (Equation 3).

$$Labour_{Cost} = Labour * Labour_{value} \tag{3}$$

Crop sub-model

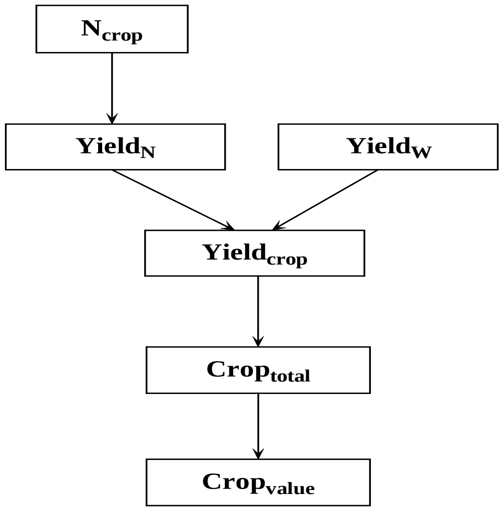


Figure 5.3. **The Crop sub-model.** Predicts crop yield as a function of available water or nitrogen.

The annual crop yield has been assumed to be primarily a function of two factors: nitrogen in soil and available water, therefore the crop model has been developed on the basis of this assumption. Firstly the yield-nitrogen model is discussed and then an overview of the yield-water relationships will be provided.

The relationship between yield and nitrogen has been assumed to be exponential as proposed by Loomis and Connor (1998) (Figure 5.5). Although this model has been specifically developed for maize, we have assumed that it can be generalised.

The two main model parameters are the crop maximum yield (Y_{max}) and the amount of nitrogen and water that produces half of the maximum yield (N_h), (Equation 4). These two parameters are strongly site and species dependent; therefore values based on measurements or realistic estimates are essential to produce an accurate prediction.

$$Yield_N = Y_{max}\left(1 - e^{-0.69(N_a/N_h)}\right) \qquad (4)$$

where

Y_{max} is the maximum yield that is possible to obtain for the considered crop (t ha^{-1})

N_a is the Nitrogen available at the farm (kg)

N_h is the level of nitrogen which produces half the maximum yield (kg)

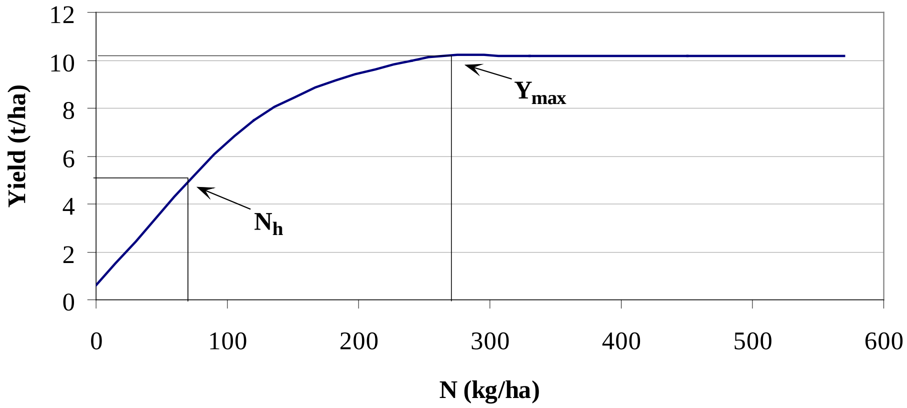


Figure 5.4. **Crop Yield Relationship.** The crop yield (t/ha) is assumed to be related to nitrogen (t ha^{-1}) and to water (mm) available in soil by an exponential function. Two parameters are required in order to describe the relationship, Y_{max} and N_h, W_h.

The nitrogen available has been assumed to derive from the manure, which is produced by the animals present on the farm (and to be 2.15% of manure mass) (Kourik, 1986).

The available water is the second environmental factor that can limit the crop yield. However measurements of crop yield response to different levels of water content were not available it has been assumed that the response of plants to available water follows a similar exponential trend of the Yield-Nitrogen model, (Equation 5).

$$Yield_W = Y_{max}\left(1 - e^{-0.69\,(W_a / W_h)}\right) \quad (5)$$

where

Y_{max} is the maximum yield that is possible to obtain for the considered crop (t ha^{-1})

W_a is the available water (mm)

W_h is the amount of water that produces half of the Yield (mm)

Limited water or nitrogen in soil strongly influences the plant's growth rate, therefore the most realistic estimation of crop yield is assumed to be the lowest between the Equation 4 and 5 predictions, (Equation 6).

$$Crop_{yield} = \min(Yield_N, Yield_W) \quad (6)$$

The monetary value of each crop cultivated is calculated as a function of the total crop harvest (kg) (Equation 6) and the crop market value (TAS), (Equation 7).

$$Crop_{tot} = Crop_{yield} * Crop_A * Farm_A \quad (7)$$

$$Crop_{value} = Crop_{tot} * Crop_{value} * 1000 \quad (8)$$

where

$Crop_A$ is an optimised parameter, which defines the portion of the farm area designed for the crop cultivation (0-1)

$Farm_A$ is the total farm area (ha)

$Crop_{value}$ is the market value of the considered crop (TAS)

Water available sub-model

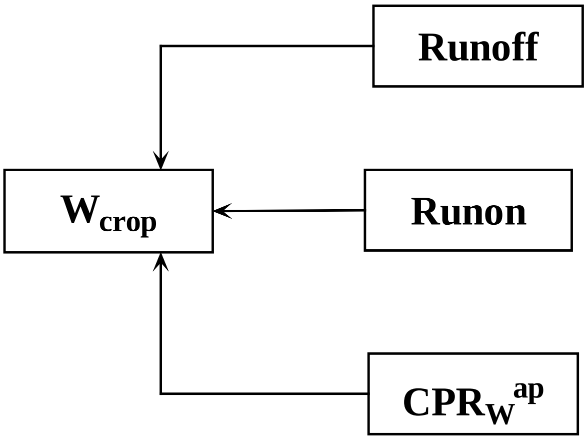


Figure 5.5. **The Water available sub-model** is formed by four main variables.

The available water (W_a) is estimated as a function of the rainfall, slope, runoff and runon, (Equation 9). The *Runoff* represents the volume of water lost, which is considered to be positively correlated to the average farm slope, (Equation 10). *Runon* is the volume of water which flows into the field from the surrounding areas and which is captured within the field (Equation 11).

$$W_a = Rain + Runon - Runoff + CPR_W^{ap} \tag{9}$$

$$Ruonoff = -Rain * Slope * 10 \quad 20 \tag{10}$$

$$Runon = \frac{Runoff * Runoff_{CE} * RWH_A}{Planted_A} \tag{11}$$

where

Rain is the mean annual rainfall (mm).

CPR_W^{ap} is the estimated volume of water that can be extracted from the common reservoir.

Slope is the field slope.

$Runoff_{CE}$ is the Runoff Water Capture Efficiency factor (0-1).

RWH_A is an optimised parameter which indicates the fraction of the farm area used for rain water harvesting (0-1).

$Planted_A$ is the farm area designed for cultivation (ha).

Common Pool Resources Model

CPRs may be a beneficial management approach for communities that have only limited resources. If a CPR approach is successful then all community members receive a fairly allocated share of the resource. If the resource is not shared fairly then the CPR approach cannot be considered to be successful. The implementation of a CPR approach by a local community is usually only undertaken if it is recognised to be beneficial in terms of profit. The CPR sub-model allows for the consideration of the effects of a CPR management approach in farm and community-based profit calculations.

The Tanzania Farm model estimates the farm profit by optimising five model parameters: cultivation area of each crop (ha), N applied to each crop (kg ha^{-1}) and the RWH area. However, if the CPR approach is included in the calculation an extra parameter is optimised i.e. the optimal volume of water (m^3) that should be extracted from the community reservoir by each farm. This value is limited by the maximum volume of water that a given farmer is allowed to extract.

When applying CPR management techniques (in particular reference to the allocation of communal water resources) it is important to assume that all participants in the process are seen as equal, and hence get an equal share of the resource. Equality amongst farmers in Tanzania is attained through village meetings whereby village leaders have the opportunity to discuss future resource management methodologies with members of the community. These discussions help the farmers to understand how their participation in various initiatives is essential to their success, for example in the allocation of water resources fairly amongst all community members (Personal Communication, Kajiru, 2001). If the assumption of equality is not made then CPR management will more than likely be regarded as unfair and will collapse. The application of wealth ranking can help in determining the value of CPR to different socio-economic groups, e.g. its potential to make a poor farmer self-sufficient in food or a rich farmer increase his profit.

Social factors have been derived for the development of wealth ranking and each is associated with a wealth index (*SEf*) (1-5) and with a weighting factor (W_{SEf}), which establishes the importance of each factor on the final social hierarchy index.

$$SHI = \frac{\sum_{i} SEf_i * W_{SEfi}}{\sum_{n}\sum_{i} SEf_i * W_{SEfi}} \tag{12}$$

where

SEf is the wealth index, ranging between 1 and 5 that is associated to poverty and wealth respectively.

W_{SEf} is the weighing factor. The higher it is more the influential the factor is on the estimation of the Social Hierarchy Index.

i is the number of socio-economic factors.

n is the number of farms in the community.

Profit sub-model

The total farm profit (P_F, TAS) is assumed to be positively correlated to the crops value and negatively correlated to costs, i.e. labour, (Equation 13).

$$P_F = \quad -Labour_{Cost} \quad \sum_{i=1}^{n} (Crop_{value})_i \tag{13}$$

The cost of fertiliser is not considered in Equation 13, as it is assumed that all the nitrogen used is derived from manure available on the farm due to the presence of animals.

5.5.3 DSS – user interface

The design of the user-interface was initiated by the researchers at The University of Nottingham. The ideas were expressed to Dr Tarsitano (who was employed for a period of 3 months to help with the programming of the DSS) to ensure the feasibility of the design would fit with the programming approach that was to be adopted.

The software comprises a main window, which is divided into three sections (Figure 5.6): the top part where the functional buttons are located, the middle section which allows model input for the two management plans and finally the bottom display where the model outputs are reported.

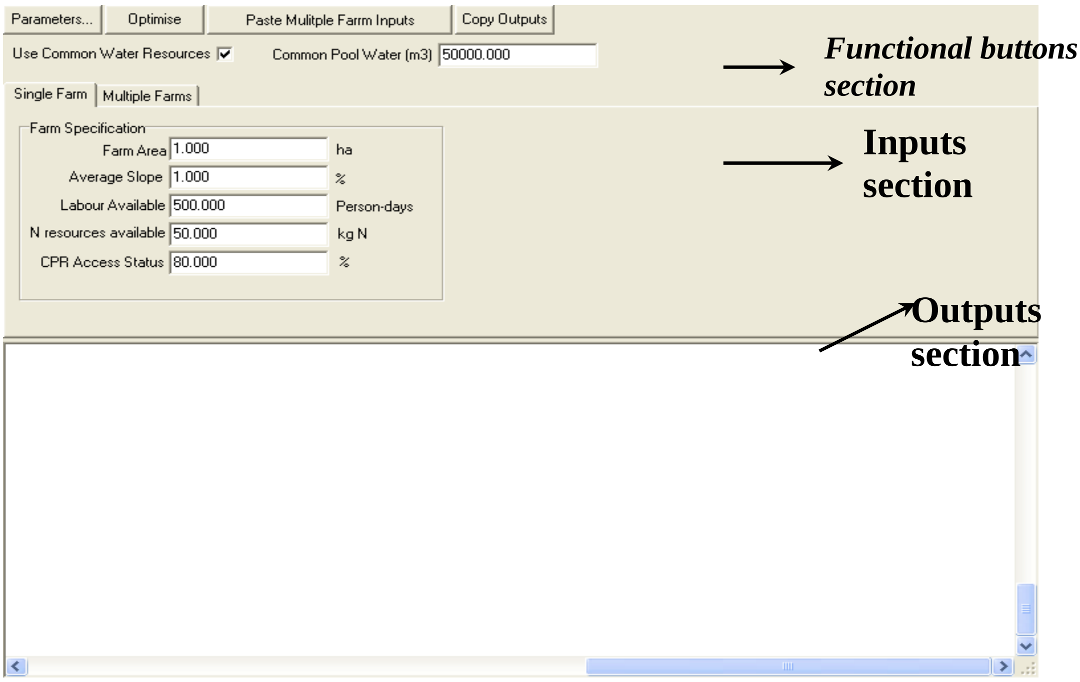


Figure 5.6. **User Interface.** The main window is divided into three sections: the functional buttons, the inputs and the outputs section. The sections are described below. The values given under the ‘Farm Specification’ are default values provided by Mr Siza Tumbo a member of the Tanzanian research team.

Functional Buttons

Within all the example screen shots detailed below, the observed values are default values that have been inputted on the screen to represent the ability to input values.

The values were provided by the team in Tanzania to be used as default values when testing the relationships that have been inputted within the model.

The top section consists of four functional buttons:

- The ***Parameters*** button allows the user to access the model parameters and set the model to represent the scenario under investigation.

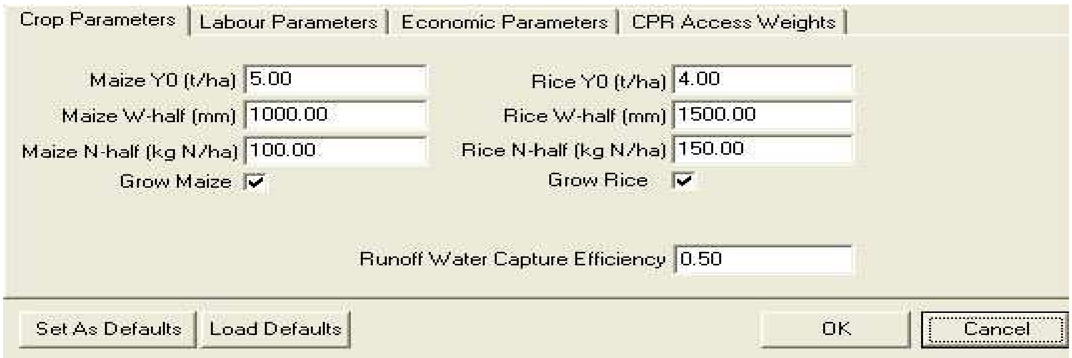


Figure 5.7. **Crop Parameters.** In the Crop Parameters settings menu, the user can enter the three main parameters required by the crop model.

- The ***Crop Parameters*** (Figure 5.7) section displays all the parameters which are required by the crop yield models to estimate the crop yield as a function of the N and water present in the farm. Check boxes allow the user to control which crops are to be included in the simulation.
- The ***Labour Parameters*** (Figure 5.8) section allows the user to customise the amount of labour required for crop cultivation, the maintenance of the RWH area, the application of fertilizers and finally the labour required to access the common water pool.

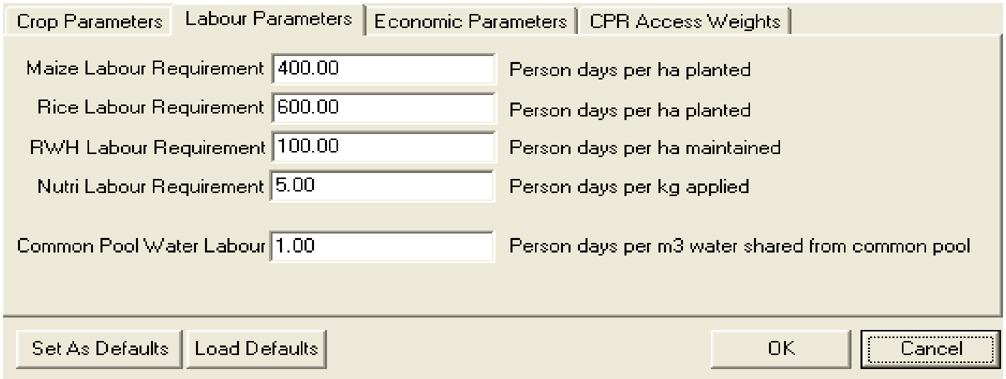


Figure 5.8. **Labour Parameters.** In the Labour Parameters settings menu the user can insert site-specific figures for the labour required for the cultivation of crops and for the management of the RWH and CPR.

To produce a realistic evaluation of the farm profit, the fixed costs related to both crops (e.g. seeds), their market value (TAS kg^{-1}) and labour expenses are entered in the edit boxes of the ***Economic Parameters*** (Figure 5.9) section.

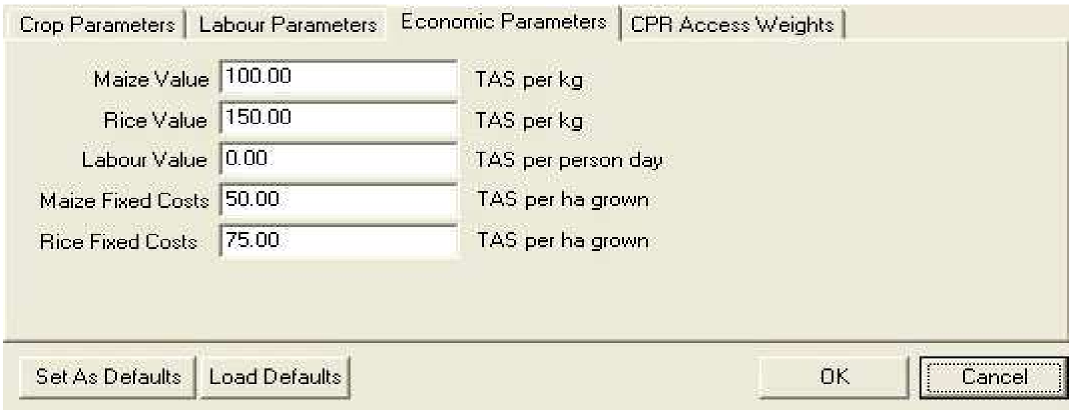


Figure 5.9. **Economic Parameters.** The final model output is the farm profit (TAS). To accurately predict this, the user should use realistic figures for the crops and labour value.

The final parameters required by the model, if the CPR management plan is included, are the CPR access weighting factors (Figure 5.10). As indicated previously, the higher the weighting factor, the more influential it is on the estimation of the Social Hierarchy Index.

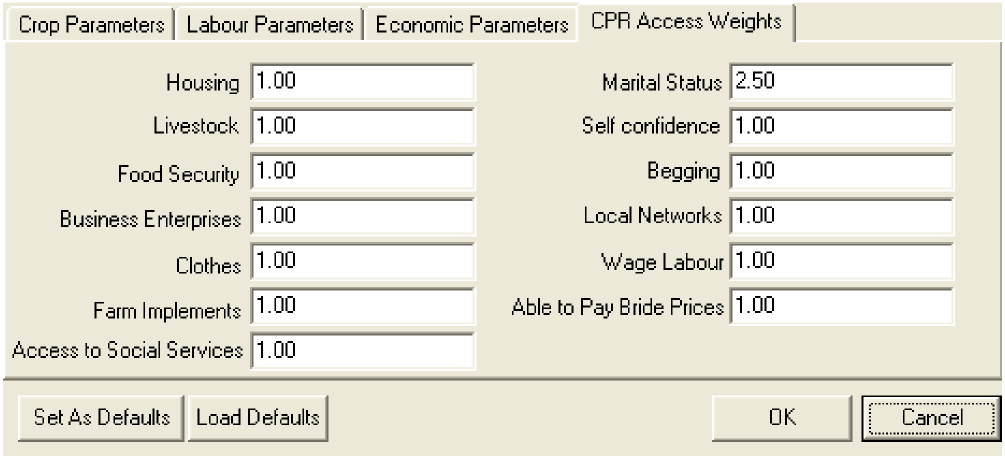


Figure 5.10: **CPR Parameters.** The CPR Access Weights menu allows the user to customise the weight that each socio-economic factor has on the final estimation of the Social Hierarchy Index. The values in the above screen shot are just representative figures illustrating how it is possible to input values in the fields. The higher the value the more influential the parameter is with regard to CPR Access Weights, from the perspective of the farmer using the system. If a farmer feels a parameter is not of significance to them, a value of zero (0) can be input.

The criteria stated above can be seen as representing wealth ranking. Therefore, when a farmer chooses values for these criteria they are in fact giving an indication of their perception of their wealth. This perception links with the concept of CPR criteria as stated by Ostrom (1990) as it helps to give the extension officer who is using the DSS a better understanding of the individual farmer or group of farmer's self perceptions and a better socio-economic understanding of the community. This in turn will help in determining whether there is likely to be compliance or conflict amongst the community members which is a fundamental point within the CPR management criteria.

Once the parameters have been customised to represent a realistic scenario, they can be set as defaults by clicking on the ***Set As Defaults*** button. If required, the default values can be reloaded using the ***Load Default*** button.

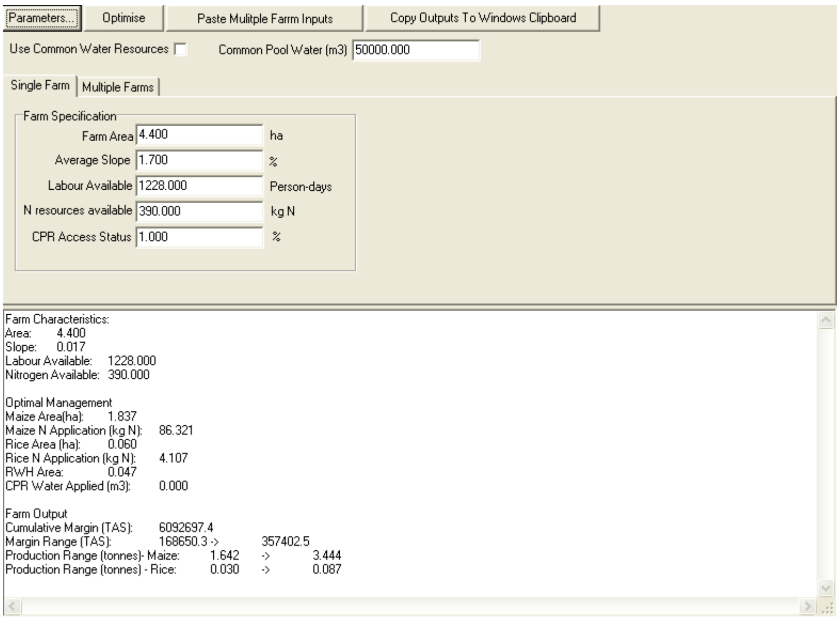
With the second button ***Optimise,*** the model can be run and the optimum values for the crop cultivation area (ha), the amount of N required (kg ha^{-1}) and RWH area (ha) etc can be estimated.

The third functional button ***Paste Multiple Farm Inputs*** enables the user to import the input data required to run a multi-farm estimation.

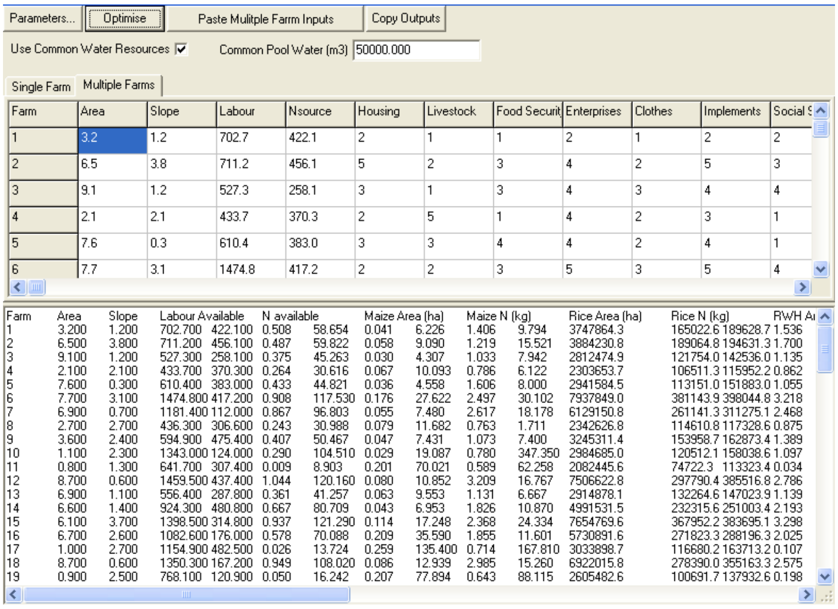
Finally, to copy the model outputs to an Excel spreadsheet to create graphs or perform data analysis, the ***Copy outputs to Windows Clipboard*** button can be used.

5.5.4 Model inputs

The middle section of the window allows the selection of Single or Multi Farm estimation (Figure 5.11). In the former, the farm characteristics should be introduced in the appropriate edit boxes. While selecting Multiple Farms estimation, the farm's characteristics such as area (ha), slope etc. have to be created in an Excel spreadsheet and then pasted using the Paste Multiple Farm Inputs button.



(a)



(b)

Figure 5.11. **<u>Farm Options.</u>** In the window's middle section, the user can select the type of farm management, Single Farm or CPR, by selecting the Use Common Water Resources (CWR) option. The model can be run for a single farm (a) or multiple farms (b). In the bottom section the model outputs are reported.

The farms characteristics table must respect the formatting reported in Table 5.2. The first column must always report progressive numbers from 1 to n (considering n as the total number of farms present in the region) the second column has to report the farm area and so on.

FarmID	Area	Slope	Labour	Nresource	Housing	Livestock	FoodSecurity	Enterprise	Clothes	Implements	Social Services	FarmInputs	Married	Self Confidence	Begging	Local Networks	WageLabour	BridePrices
1																		
…																		
…																		
n																		

Table 5.2. **Farm characteristics table.** The input data for a multi farm evaluation have to be inserted in a specific order as shown in the table above.

To perform the calculation including the CWR, the ***Use Common Water Resources*** box should be checked and the volume of the common water pool given in the Common Pool Water (m^3) edit box.

5.5.5 Model Output

The lower part of the window reports the model outputs, which can be copied into an Excel spreadsheet using the Copy Outputs button.

Outlined below are some example outputs that have been determined from the running of the Tanzanian Farm model. Three specific scenarios have been investigated:

1. Single farm application
2. Multiple farm application
3. Addition of the CPR attribute – this is covered within the running of the single and multiple farm examples

In the running of these examples, various assumptions have been made and parameters fixed. For the single farm and multiple farm scenarios, the crop, labour and economic parameters have been fixed at the default settings. Within the multiple farm option, the CPR access weights have been altered. The reason for this is to be able to represent different farmer criteria. Limits have to be applied to the figures that can be inputted within the model. These are specified in table 5.3 below.

Parameter	Min	Max	Reason
Area	0.5 ha	10 ha	Limits have to be specified for the farm size for the determination of the best allocation of land for crops
Slope	0%	4%	Relief of land influences the movement of resources from one field to another and this needs to be accounted for
Labour	300	1500	Labour in man days affects the agricultural practices that can be performed
Nresource	50	500	Limits to the levels of nitrogen that can be added are given to help show the affects of varying levels of application
Housing	0	5	Importance specified by farmer
Livestock	0	5	Importance specified by farmer
Food security	0	5	Importance specified by farmer
Enterprise	0	5	Importance specified by farmer
Clothes	0	5	Importance specified by farmer
Implements	0	5	Importance specified by farmer
Social status	0	5	Importance specified by farmer
Farm inputs	0	5	Importance specified by farmer
Married	0	5	Importance specified by farmer
Self confidence	0	5	Importance specified by farmer
Begging	0	5	Importance specified by farmer
Local networks	0	5	Importance specified by farmer
Wage labour	0	5	Importance specified by farmer
Bride prices	0	5	Importance specified by farmer

Table 5.3: The numerical limits applied to the parameters utilised within the Tanzanian DSS.

The data used for the following DSS examples has been derived by proxy, such that it was provided to the team in Nottingham by the scientific researchers working in Tanzania. No additional experimentation and data capture was performed for obtaining these data sets. This can be seen as a limitation and constraint to the results and outputs that are expressed below. However, in the context of this research, the outputs can be viewed as representative examples which illustrate the potential that this DSS possesses: notably the extrapolation of different water and nutrient management approaches for farmers with differing wealth classifications and perceptions.

5.5.5.1 Single farm example

For the single farm scenario, 4 runs of the model have been carried out.

1. The first run utlisises all the default settings in the model when the program is first opened by the user. No additional nutrients or water resources are added.
2. The second example details the differences between the first run (control) of the model and a run that includes the application of the common water resource (CWR).
3. The third run is similar to the first but the level of nutrient application has been increased.
4. The fourth follows the same lines as the third, introducing the CWR element as well as the elevated level of nutrient application.

Comparisons between all 4 shall be carried out.

The screen shot below (Figure 5.12) highlights the areas that are utilised within the model for the single farm runs.

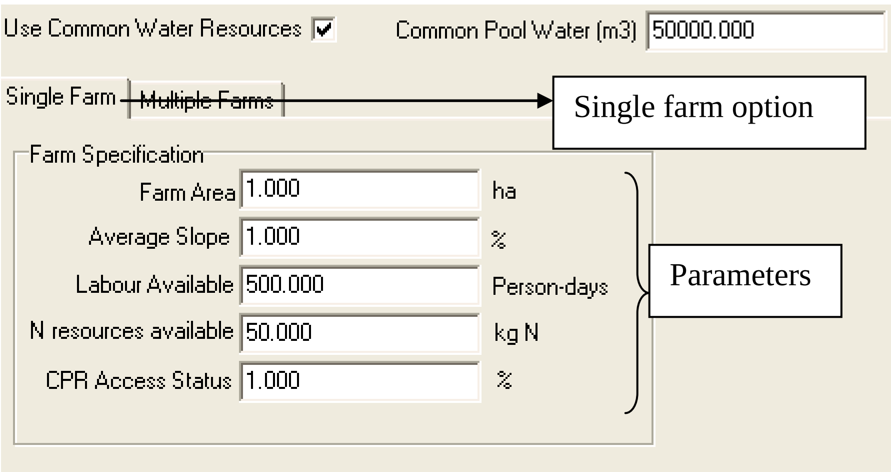


Figure 5.12: Screen shot to illustrate the single farm parameters

On running the model with the specified parameters, the output is viewed in the ‘output window’. The output can then be copied into an Excel file for further analysis. The following tables detail the outputs that were copied into Excel for the 4 runs detailed above.

The outputs for the various runs share common observations. Details related to the inputted ‘Farm Characteristics’ are stated – this is the information that would be provided by the farmers and then used by the extension officers utilising the tool. In the context of these examples, the information has been provided by the team in Tanzania, primarily Mr Siza Tumbo and Mr Geophrey Kajiru. The next section of information that can be determined is the ‘Optimal Management’. Within the section the optimal area for maize and rice production is detailed, alongside the levels of nutrients to be applied for optimal crop production. RWH and CPR water are also stated. The final aspect is related to the monetary ‘Farm Output’. Potential production ranges are expressed for rice and maize.

Run 1 – control run using default parameters

Run 1	Input and output values		
Farm Characteristics:			
Area:	1	(hectares)	
Slope:	0.01	(slope percentage)	
Labour Available:	500	(person days)	
Nitrogen Available:	50	(kg N)	
Optimal Management			
Maize Area(ha):	0.706	(optimal management	
Maize N Application (kg N):	36.072	options for the two	
Rice Area (ha):	0.039	crops)	
Rice N Application (kg N):	2.754		
RWH Area:	0.003		
CPR Water Applied (m3):	0	(Additional water)	
Farm Output		(outputs/ranges)	
Cumulative Margin (TAS):	2545318.8		
Margin Range (TAS):	70380.4	->	149983.8
Production Range (tonnes)- Maize:	0.673	->	1.412
Production Range (tonnes) - Rice:	0.02	->	0.059

Table 5.4: **Run 1**. Results from using the default parameters

Initial observations from this output (Table 5.4) show that maize would be the preferred crop to grow under these conditions giving a greater yield range than rice. This increase in yield can be attributed to the greater volume of nitrogen applied (Loomis and Connor, 1998; Vanlauwe *et al*, 2002). Also the area of land given over to the production of maize is greater than that of rice. This increase in cultivable land given over for maize production will clearly benefit maize yields per unit area.

Run 2 – addition of the CWR attribute

Run 2	Input and output values		
Farm Characteristics:			
Area:	1	(hectares)	
Slope:	0.01	(slope percentage)	
Labour Available:	500	(person days)	
Nitrogen Available:	50	(kg N)	
Optimal Management			
Maize Area(ha):	0.743	(optimal management	
Maize N Application (kg N):	38.265	options for the two	
Rice Area (ha):	0.004	crops)	
Rice N Application (kg N):	0.239		
RWH Area:	0.013		
CPR Water Applied (m3):	6.033	(Additional water)	
Farm Output		(outputs/ranges)	
Cumulative Margin (TAS):	2570333		
Margin Range (TAS):	71494.5	->	150342.9
Production Range (tonnes)- Maize:	0.711	->	1.495
Production Range (tonnes) - Rice:	0.002	->	0.005

Table 5.5: **Run 2**. Addition of the common water resource

With the addition of the common water resource the production ranges for the crops have changed (see Table 5.5). Maize production has increased alongside the area of land that should be partitioned to the growing of maize. Conversely the levels associated to rice have fallen as a greater volume of resource (water and nitrogen) has been partitioned to the growing of maize. A simple conclusion here would be to state that the addition of the extra water resource is of greater benefit to the production of maize. Maize is the crop that is seen to suit the management processes displayed within this example (Run 2).

Run 3 – increasing the level of nutrients

Run 3	Input and output values		
Farm Characteristics:			
Area:	1	(hectares)	
Slope:	0.01	(slope percentage)	
Labour Available:	500	(person days)	
Nitrogen Available:	100	(kg N)	
Optimal Management			
Maize Area(ha):	0.712	(optimal management	
Maize N Application (kg N):	36.126	options for the two	
Rice Area (ha):	0.033	crops)	
Rice N Application (kg N):	2.167		
RWH Area:	0.039		
CPR Water Applied (m3):	0	(Additional water)	
Farm Output		(outputs/ranges)	
Cumulative Margin (TAS):	2539382.1		
Margin Range (TAS):	70516.1	->	148671.3
Production Range (tonnes)- Maize:	0.679	->	1.417
Production Range (tonnes) - Rice:	0.017	->	0.047

Table 5.6: **Run 3**. Increasing the levels of nutrient applied

For this example (Table 5.6) the level of nitrogen available has increased from 50 kg N to 100 kg N. No additional water has been added. Comparing this to Run 1 (Table 5.9), the production of maize has increased, but only very slightly. One would expect to see a greater increase in yield. This small increase could be attributed to the other factors (water availability) that may be influencing the yield production of maize. Rice on the other hand has shown little change in yield from the addition of more nitrogen signifying that nitrogen application at these levels (50 kg N or 100 kg N) have a similar affect on the production of rice.

Run 4 – increased nutrients and water resource

Run 4	Input and output values		
Farm Characteristics:			
Area:	1	(hectares)	
Slope:	0.01	(slope percentage)	
Labour Available:	500	(person days)	
Nitrogen Available:	100	(kg N)	
Optimal Management			
Maize Area(ha):	0.709	(optimal management	
Maize N Application (kg N):	35.935	options for the two	
Rice Area (ha):	0.029	crops)	
Rice N Application (kg N):	1.86		
RWH Area:	0.033		
CPR Water Applied (m3):	6.553	(Additional water)	
Farm Output		(outputs/ranges)	
Cumulative Margin (TAS):	2517692		
Margin Range (TAS):	70194.6	->	147001.9
Production Range (tonnes)- Maize:	0.679	->	1.409
Production Range (tonnes) - Rice:	0.015	->	0.04

Table 5.7: **Run 4**. Increasing both the level of water and nutrient applied to the single farm.

With the addition of the common water resource, little change in the outputs (Table 5.7) is observed signifying a plateau between water and nutrient application for the increasing of crop production. Also, comparing this result to that shown in Run 2 (Table 5.5) whereby only the water resource applied was increased, illustrates how water is the factor that has the most influence on increasing the production of maize.

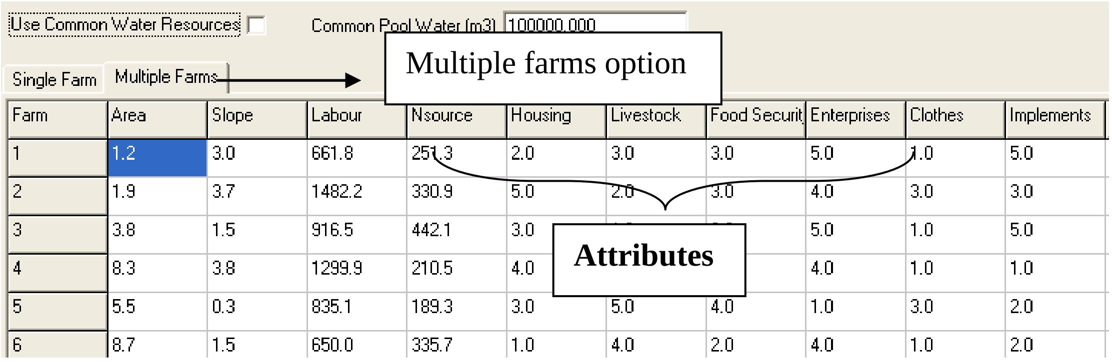
It must be noted however that these observations are only true for the examples that have been stated above.

5.5.5.2 Multiple farms example

The multiple farms example allows the extension officer who is using the system to determine the best management options for more than one farm, i.e. a community of farmers.

To help in utilising this function of the Tanzanian Farm model an Excel template spreadsheet has been set up that allows all the inputs related to topography and CPR criteria weightings to be recorded easily. This template can subsequently be pasted into the model and the optimisation process carried out. The projected results from this method show the management options available to the farmers who inputted their farm details into the template.

A maximum of 100 farms can be optimised at the same time. For the given example only 10 farms have been utilised.



Farm	Area	Slope	Labour	Nsource	Housing	Livestock	Food Securit	Enterprises	Clothes	Implements
1	1.2	3.0	661.8	251.3	2.0	3.0	3.0	5.0	1.0	5.0
2	1.9	3.7	1482.2	330.9	5.0	2.0	3.0	4.0	3.0	3.0
3	3.8	1.5	916.5	442.1	3.0	[illegible]	[illegible]	5.0	1.0	5.0
4	8.3	3.8	1299.9	210.5	4.0	[illegible]	[illegible]	4.0	1.0	1.0
5	5.5	0.3	835.1	189.3	3.0	5.0	4.0	1.0	3.0	2.0
6	8.7	1.5	650.0	335.7	1.0	4.0	2.0	4.0	1.0	2.0

Figure 5.13: A screen shot to demonstrate the attributes that have to be completed for the running of the multiple farm aspect of the Tanzanian DSS. The values observed in this screen shot are numerical values inputted and provided by the team in Tanzania.

The above screen shot (Figure 5.13) illustrates how the model appears when using the 'multiple farms' option.

When pasting in the information from the Excel template it is essential that the data remain in the same format as the column headings/positioning, are linked with the equations used within the model.

Two runs have been carried out for the 10 farms used in the example. The first run utilises the default model settings, the second run incorporates the addition of the common water resource.

The 'Farm Characteristics' provided for the 10 farms used in these examples was provided by the team in Tanzania. It may represent actual farms in the study regions. However in the context of these examples, the data was provided simply for test purposes to illustrate the types of results that can be observed from using the Tanzanian DSS.

Run 1 – multiple farms without CPR water application

Farm	1	2	3	4	5	6	7	8	9	10
Area	5.5	8.2	9.9	7.8	5.8	1	1.2	3.8	9.1	3.9
Slope	3.4	3.7	0.6	3.8	3.4	0.6	2.4	2.4	2.2	3.6
Labour Available	499.8	1198.3	686.1	1172.8	1015.6	1271.9	1382.1	410.2	1025.6	724.8
N available	403.8	110.4	414.6	151.9	470.6	371.5	233.2	247.1	458	127
Maize Area (ha)	0.359	0.051	0.486	0.905	0.752	0.075	0.01	0.287	0.689	0.535
Maize N (kg)	41.869	4.846	57.877	112.93	89.401	76.24	6.606	36.054	85.477	66.832
Rice Area (ha)	0.042	0.737	0.037	0.024	0.059	0.166	0.322	0.031	0.098	0.033
Rice N (kg)	6.025	105.2	5.246	4.703	9.587	65.447	203.83	4.167	14.855	5.5
RWH Area (ha)	0.909	1.83	1.537	2.08	1.836	0.759	0.868	0.757	1.891	1.288
CPR Water Applied (m3)	0	0	0	0	0	0	0	0	0	0
Total Margin	2779553	5743997	3564133	6645364.1	5687790.4	2132654.1	3602140	2268689	5627479	4077647.9
Min. Margin	137292.4	287199.9	143418.6	320363.7	277614.6	69054.5	138430.6	109837.6	266769.6	200471
Max. Margin	139123.6	287199.9	182676	333140.2	284974.4	125992.3	195224.4	113641.4	282393.1	204167.2
Min. Maize Production (t)	1.236	0.157	1.343	3.125	2.585	0.229	0.041	0.997	2.352	1.894
Max Maize Production (t)	1.236	0.157	1.692	3.226	2.615	0.364	0.049	1.027	2.449	1.909
Min. Rice Production (t)	0.091	1.81	0.061	0.053	0.128	0.308	0.896	0.067	0.21	0.074
Max. Rice Production (t)	0.104	1.81	0.09	0.07	0.156	0.597	1.269	0.073	0.25	0.089

Table 5.8: **Run 1**. The results of running the Tanzanian DSS for ten farms simultaneously. No additional water resources have been added.

The outputs from this run (Table 5.7) clearly demonstrate the varied responses obtainable from running the model for multiple farms. The best crop to grow is maize, in terms of greater productivity and cropping area. Farms 1 and 5 are good examples of how an increase in nitrogen availability increases the production capability of maize. These two farms have similar areas and the same slope percentage but differ in labour and nitrogen availability. The increase in labour availability in farm 5 helps to enhance the area of land that can be cultivated for maize as more resources are available for performing the agricultural practices required. It can be observed that farms with higher labour availability have the capacity for producing greater yields of rice – for example farms 2, 6 and 7. These observations will also be influenced by the inputs given by the farmers for the CPR criteria weightings, such as their perception of how food security influences the decisions that they make with regard to agricultural management. Food security is a fundamental factor that needs to be considered when determining the effects of community decision-making processes. How a farmer perceives food security will influence any potential management strategies that may be applied. The objective of the Tanzanian DSS is to promote sustainable agriculture. Therefore from the calculations displayed in the multiple farm examples, it is important to make sure that all farms display some benefit from the application of resource management techniques and CPR.

Run 2 – introducing the application of the CPR water

Farm	1	2	3	4	5	6	7	8	9	10
Area	5.5	8.2	9.9	7.8	5.8	1	1.2	3.8	9.1	3.9
Slope	3.4	3.7	0.6	3.8	3.4	0.6	2.4	2.4	2.2	3.6
Labour Available	499.8	1198.3	686.1	1172.8	1015.6	1271.9	1382.1	410.2	1025.6	724.8
N available	403.8	110.4	414.6	151.9	470.6	371.5	233.2	247.1	458	127
Maize Area (ha)	0.309	0.869	0.447	0.725	0.715	0.012	0.014	0.271	0.62	0.544
Maize N (kg)	38.769	99.513	52.451	91.484	86.541	39.02	4.892	32.531	73.271	67.225
Rice Area (ha)	0.062	0.087	0.066	0.15	0.077	0.234	0.322	0.039	0.149	0.025
Rice N (kg)	9.742	10.559	9.021	25.18	10.55	80.566	174.93	6.787	25.171	3.535
RWH Area (ha)	0.854	2.12	1.471	1.975	1.793	0.754	0.862	0.735	1.864	1.277
CPR Water Applied (m3)	11.001	35.718	12.525	11.861	17.996	449.26	192.68	7.977	8.99	11.092
Total Margin	2688693	6494250	3465009.5	6391962.4	5565649.8	2237561	3598655	2206543	5485626	4032076.2
Min. Margin	132105.1	317693.6	137334.7	311139.2	272287.8	75316.8	137313.1	105912.8	264519.6	194831.8
Max. Margin	134632.9	325101.1	178137.7	320454.7	278663.5	132010	195290.2	110779	275374	201998.1
Min. Maize Production (t)	1.105	2.906	1.212	2.598	2.472	0.039	0.059	0.934	2.149	1.869
Max Maize Production (t)	1.105	2.962	1.544	2.598	2.51	0.058	0.07	0.948	2.149	1.929
Min. Rice Production (t)	0.144	0.181	0.108	0.342	0.167	0.476	0.876	0.084	0.331	0.053
Max. Rice Production (t)	0.161	0.193	0.158	0.405	0.184	0.841	1.255	0.107	0.403	0.061

Table 5.9: **Run 2**. The results from running the Tanzanian DSS for the same ten farms as Table 5.7, but this time the CPR water has been applied.

With the application of the CPR water it is evident that there is a shift in production capacities for the two crops. This can be observed by looking at the results for farm 2 (see Table 5.9). Run 1 demonstrated how rice would benefit more from the practices being utilised for farm 2. However, following the application of CPR water, maize is the crop that performs best and this is reflected by the fact that a greater cropping area has been allocated to maize in this scenario. It is also observed that farms from run 1 that showed high levels for maize production (e.g. farm 4 and 9) still show high levels for maize production following the application of the CPR water. This highlights how the model is reflecting farmers existing practices. They also show an increase in rice production demonstrating the benefits for crop production for these two farms (4 and 9) following the application of the CPR water. From this run it is possible to state how some farms benefit from the application of the CPR water more than others. This can be determined by comparing the total margins observed. For example farm 1 has a greater margin in run 1 than run 2, while on the other hand farm 2 shows a greater margin in run 2. The reason for this decline in margin for farm 1 is related to the decline in maize production and therefore less income will be being generated from its production. While farm 2 shows an increase in production for both crops and therefore there will be an increase in income being made from the crops.

Table 5.10 states the benefits and costs for this community of adopting CPR.

Farm Number	Benefits	Costs
1	- An increase in rice production.	- Decrease in maize yield and land partitioned to maize production - Decrease in total margin
2	- An increase in both maize and rice yield production - Greater total margin observed	
3	- A slight increase in rice yield - Increase in total margin	- Decrease in maize yield
4	- Greater partitioning of resource to the production of rice	- Fall in yield for maize
5	- Maize production remains fairly even between the two runs - Rice yields increase	
6	- Slight increase in rice yields	- Quite a decline in the yield of maize
7	- Both crop yields remain level between the two runs	- Cropping areas remain similar
8	- A slight increase in rice production while maize remains constant	
9	- Maize production remains constant - Rice shows an increase in production	
10	- Constant production levels for both rice and maize	- Application of CPR shows little benefit. Agricultural practices can remain the same

Table 5.10: The benefits and costs displayed by the 10 example farms in the multiple farm model example.

The model runs demonstrated for both the single farm and multiple farms scenario help to highlight the different attributes of the Tanzanian DSS model. They show how the application of additional resources in some instances (see Table 5.10) can be of benefit to the farmers. It is ultimately up to the communities in question as to whether they adopt the potential practices for water and nutrient management displayed by these outcomes. The interactions between water and nitrogen application are illustrated by the single farm model runs. Maize is the crop that benefits more from the application of additional water. This effect is also enhanced by the greater area of land being partitioned for the cultivation of maize. Within the multiple farms situation, both crops are affected by the application of the CPR water and are affected by the weighting criteria that have been specified by the farmers. Of the ten farms as shown in the examples (Table 5.8 and Table 5.9) each appear to be affected in different ways following the application of the CPR water. Some farms show increased production of both crops, some only in a single crop and others remain constant or show a decline in production. These variations arise from the partitioning of the resources available to the farmer. For example, a decline in crop production is often observed with an increase in the production of the second crop in question, such that one crop is benefiting more from the allocated resources than the other. This illustrates the complexity and variability observed in agricultural management and crop yield production following the application of management techniques (Azam-Ali *et al,* 2002). It is often difficult to predict the exact outcomes. However, the Tanzanian model helps to illustrate potential outcomes from management intervention.

5.5.6 Application of outputs

By running the Tanzanian model for both single farms and multiple farms, it has been possible to demonstrate the potential outputs from the DSS. It must be noted that these examples are only illustrative. Through physical testing of the system in the field and the collection of true data for runs, a more reliable set of outcomes could be observed.

The manipulation and application of the data collected throughout this project has brought about the development of three products. These products can be used singularly or combined together.

Firstly there is the production of the DSS for RWH management. This is the main output from this study. The second and third products are the database and the spreadsheets, which can be used as subsidiary tools. These are closely linked as they share common functions. They both have the ability to store information and subsequently disseminate information back to the user of the system. The database stores information related to farming conditions that help to generate the most suitable agricultural management strategies that can be applied. The spreadsheets allow the user of the system to input details related to their farms and perceptions of farming practices. These can be cross-referenced with information in the database to determine the most suitable management options. The information in both systems can be supplemented by using the DSS to generate enhanced management options.

<u>Chapter Six</u>

SYSTEM DISSEMINATION AND APPLICATION

6.0 Chapter Overview

The objective of this chapter is to describe how the Tanzanian DSS and its subsequent by-products (database and spreadsheets) will be used by the end users (extension officers). The outputs from the research shall be reiterated and described in relation to how they will be of benefit to the farmers (the beneficiaries) in Tanzania.

6.1 Developed Products

The first aspect is to re-iterate the products and tools that have been developed during this research project. These have previously been discussed within chapters 3, 4 and 5.

This research project generated four products. Each can be considered alone, or can be used in conjunction with the others. The products are:

- The Tanzanian Resource Management Decision Support System (DSS)
- Agricultural Management Database
- Data Collection Spreadsheets
- Geographical Information Maps

6.1.1 The Tanzanian DSS

The Tanzanian resource management DSS is the fundamental output from this project. The DSS aims to utilise inputs related to resource levels and applications for both water and nutrients as stipulated by farmers in the field. On inputting this information to the computerised DSS, a series of management options based on the allocation of the specified resources are given to guide the end users of ways to improve crop production and maintain sustainability.

The Tanzanian DSS is a computer model that has been developed through collaboration with end users and the acquisition of suitable data sets for relationship building. It is essential that the system can be loaded onto a computer that also has Microsoft Excel capabilities. The DSS can be used by the extension officers to act as a ‘discussion point’ – such that when the extension officers receive the management options from the DSS they can then meet with the farmers to discuss the options, and decide on the best management approach for the farmer(s) in question. The outputs derived from the system are under the control of the inputs provided by the farmers in the field i.e. the outputs from the system are only as good as the information it is provided with. The outputs from the system can then be used to instigate discussions with individual farmers or groups of farmers in the villages, to help in understanding and applying better resource management techniques.

The successful use of the DSS (Figure 6.1) is dependent upon the end users understanding how to use the system, and the end beneficiaries understanding their role in the decision making process.

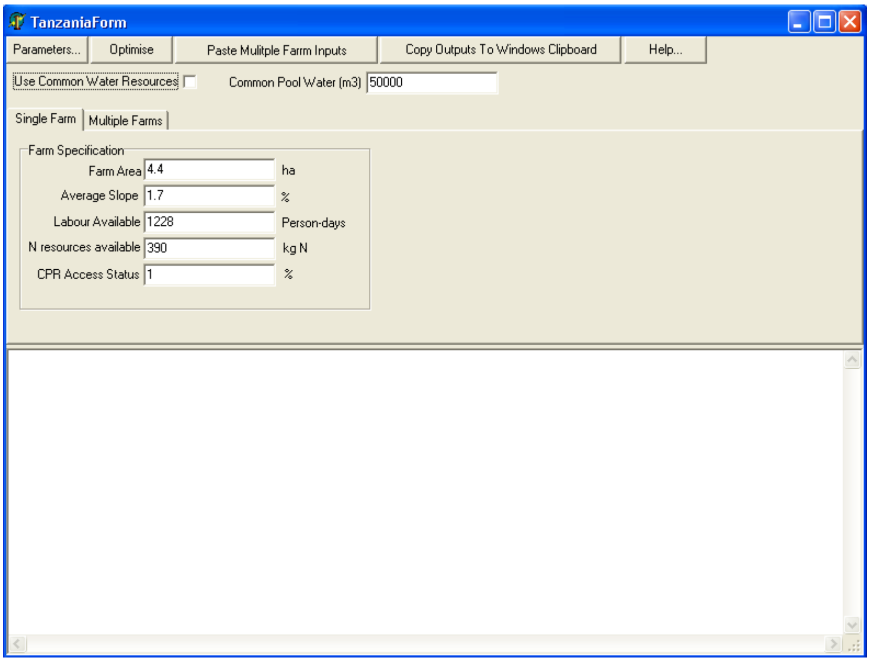


Figure 6.1: Screenshot of the Tanzanian DSS

Outlined below (Table 6.1) are the steps involved in using the Tanzanian DSS for resource management.

Step	Description	Participants
1	Existing farming conditions such as an understanding of soil type, land area and crops grown should be recorded through observation and questioning of the farmers	Extension officers and farmers in the field, community members
2	Load the Tanzanian DSS onto a computer using the provided CD-ROM. The computer is likely to be housed within the Extension Office in the District.	Operated by the extension officers.
3	Once loaded, the system is run with test data to ensure it is working properly. This will help to ensure the extension officers using the tool understand its capabilities.	Extension officers
4	Meet the individual farmers or community to discuss their needs and issues with regard to resource management on their farms. This will help determine the questions that need to be answered by using the DSS. For example the farmer may be able to stipulate the level of water they have, and want to know how this should be allocated to their crops.	Focus groups and discussions held between extension officers and the farmers.
5	Review the existing farming conditions such as an understanding of soil type, land area and crops grown with the farmers.	Extension officers and farmers in the field, community members
6	Record all information and data from the discussions for analysis purposes before applying it to the DSS.	Extension officers
7	Analyse and check the collected information and data. Ensure it is sufficient for use within the DSS.	Extension officers and scientific officers in the research station
8	Decide whether the DSS will be used for an individual farmer, or for a community (hence multiple farmers). The DSS has two options – single or multiple farm application.	This decision will be made through discussions with the community.
9	On choosing the single or multiple farm scenario, input the acquired data provided by the farmers and from observations.	Extension officers
10	Run the DSS model and obtain the results.	Extension officers
11	Record the results and decide how best to extrapolate these to the community – such as via group discussions or individual consultations, visual representations or results (graphs or tables)	Extension officers
12	Meet with the community and farmers to disseminate the results and management options.	Extension officers and community members
13	Pass the results onto the village elders for use in village meetings. They maybe able to help explain options (such as the cost and benefits of CPR) to a greater effect to the farmers	Extension officers and village elders
14	Explain the results and express how there are options that could be adopted, but do not have to be instigated.	Extension officers and farmers
15	Allow the farmers to digest the results and ask further questions.	Farmers and community members
16	The results from the DSS can be seen as a focal point for initiating discussions between farmers within a community and discussions between the farmers and extension officers regarding (community) resource management and cropping options.	All community members interested in the management of their resources
17	Apply the desired management options if the farmers feel the option is feasible etc	Farmers and extension officers
18	Review the results	Community members and extension officers

Table 6.1: Steps to show how to apply the Tanzanian DSS

The application of these steps is at the discretion of the extension officers, and it is likely to be an iterative procedure. The reason for this is that there should be continuous communication between the extension officers and the end beneficiaries (community members) during the running of the DSS. It is important for the extension officers to become familiar with the DSS before they embark on discussions with the farmers to ensure they are familiar with the potential outcomes from the system. This will help to prevent them (the extension officers) making any false promises to the farmers with regard to determining resource management options. It is important that the farmers are also aware of the capabilities of the tool so they do not raise questions that cannot be covered by the tool. The Tanzanian DSS should be seen as a starting point for initiating discussions about improving resource management, as well as providing potential methods for resource allocation and improved agricultural management techniques.

The simple flowchart below (Figure 6.2) illustrates the main steps involved in using the Tanzanian DSS and helps to show how it is important to retrace ones steps while using the tool.

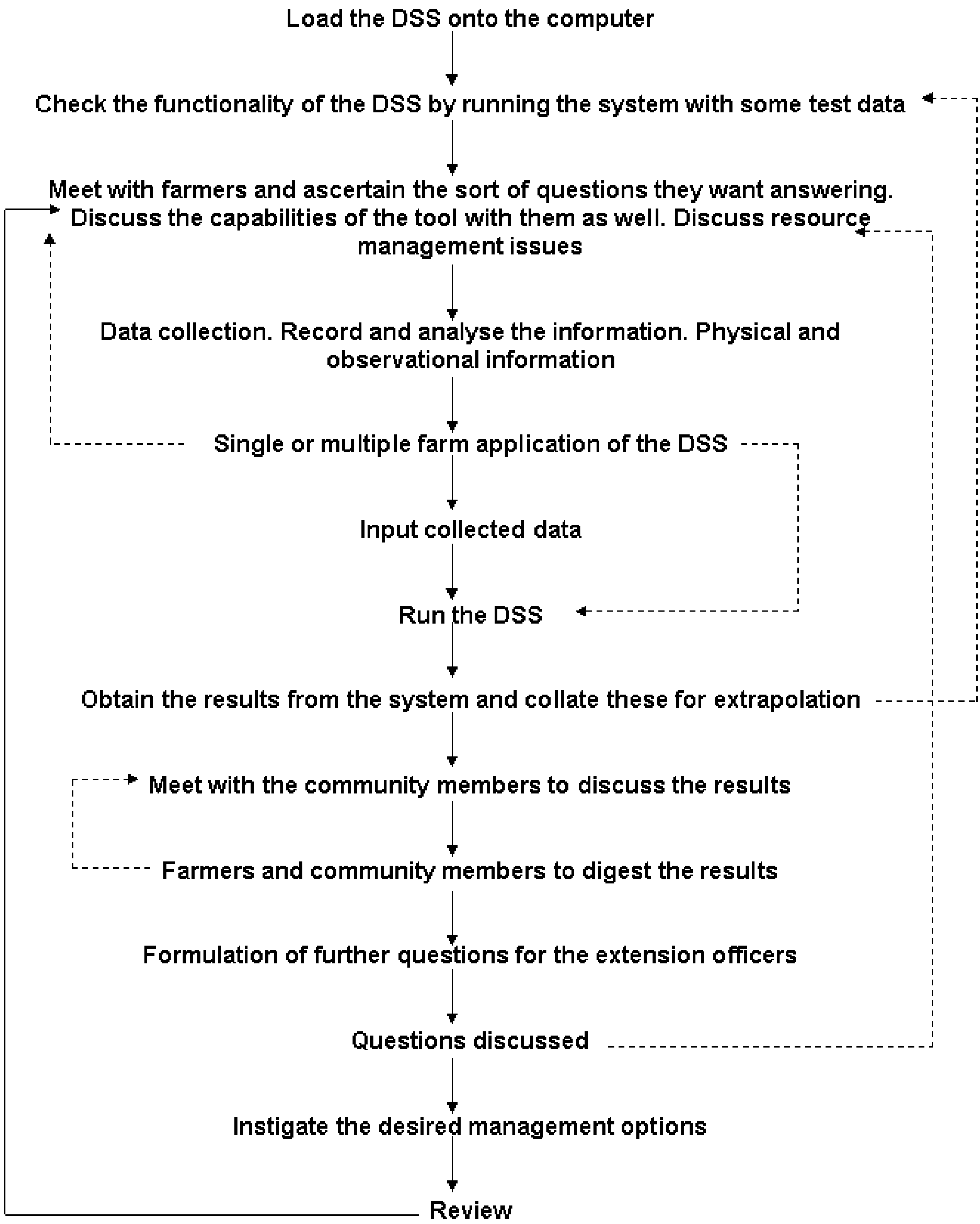


Figure 6.2: Flowchart demonstrating the application of the Tanzanian DSS

6.1.2 Management Database

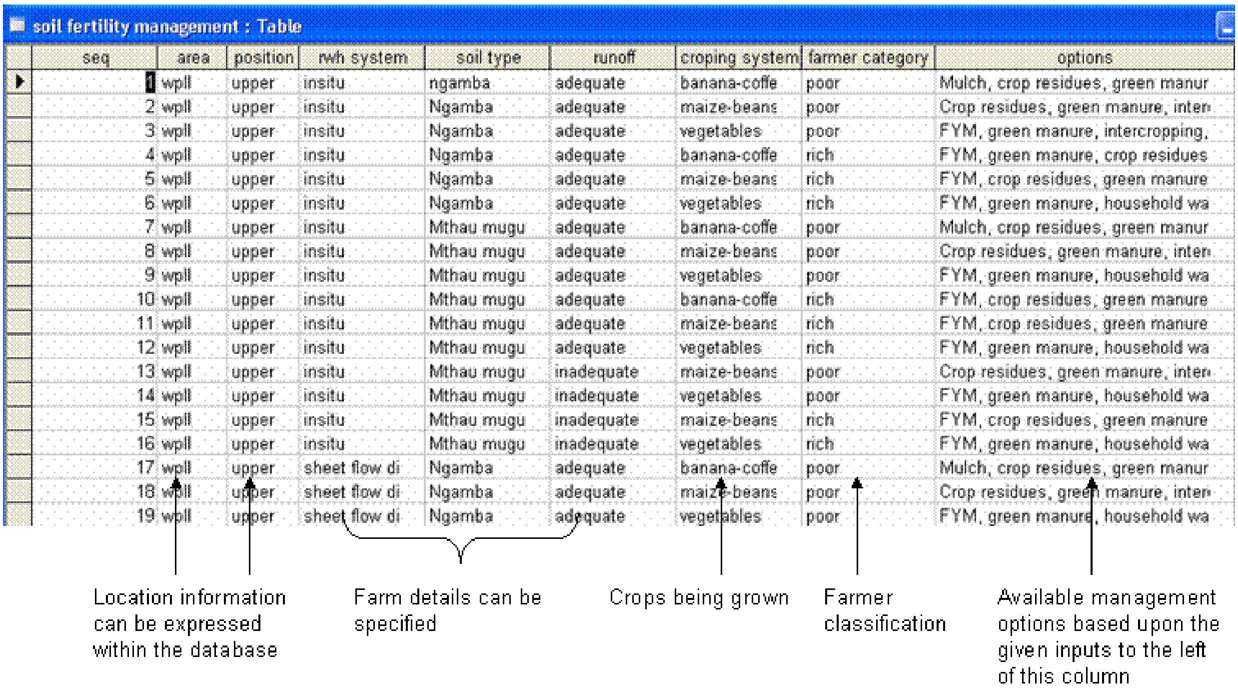
A simple relational database has been set up within Microsoft Access. The database is the output of data from questionnaires and discussions with individual farmers in Tanzania. This research was carried out by the extension officers and agricultural scientists in the catchment areas. The collected information was tabulated and disseminated to the team in Nottingham, where the database system was developed. The database can be viewed within the Appendix.

The purpose of the database is to act as a quick reference guide for potential agricultural management options. The input fields (records) within the database are related to on farm agricultural conditions – such as water application, crops being grown, soil type. Farm location information is also recorded – such as catchment area, and location within the catchment based upon region (upper, middle or lower catchment). This information was collected from farmers in the field. The final field of data that was collected was in relation to the type of agricultural practices that were being performed on the farms by the farmers being questioned. The practices were focused on determining nutrient application methods and agricultural management techniques in relation to cropping techniques and soil management strategies. These data can be seen as the output from the database, as the agricultural practices that are performed by the farmers will ultimately depend on the farm conditions such as soil type and crops being grown.

To utilise the database, the input fields such as soil conditions and location details need to be determined. This will most likely be through direct observation and discussions. Once this information is collected, the extension officers using the database can carry out various queries (searches) within the system. The resultant output will be a table that displays the inputs and the management options based on the expressed inputs. Extrapolation of this information to the farmers in the field will most likely be through discussions. However, the information from the database can easily be printed out to form quick reference booklets that display different options for farmers. These booklets can be kept either by the farmers or the extension officers and referred to as and when needed. Examples of these are in the Appendix.

This database could easily be extrapolated to other semi-arid areas of Tanzania, areas that share similar agricultural and environmental conditions such as soil type and land relief. The database could also be extrapolated to dissimilar areas if additional information is added to the structure and set up of the database. The database could be used to help understand what other crops could be grown based on a specific soil type, and this can be followed up by understanding the agricultural management options available to the farm in question. However, it must be noted that the results from the queries carried out in this database are only representative of the information that was collected from the farmers who took part in the initial questionnaires. The ultimate decision as to whether to adopt any of the options or not is up to the individual or group of farmers using the database tool.

Figure 6.3 below illustrates the fields within the database tool and the potential output management options.


soil fertility management : Table

seq	area	position	rwh system	soil type	runoff	croping system	farmer category	options
1	wpll	upper	insitu	ngamba	adequate	banana-coffe	poor	Mulch, crop residues, green manur
2	wpll	upper	insitu	Ngamba	adequate	maize-beans	poor	Crop residues, green manure, inter
3	wpll	upper	insitu	Ngamba	adequate	vegetables	poor	FYM, green manure, intercropping,
4	wpll	upper	insitu	Ngamba	adequate	banana-coffe	rich	FYM, green manure, crop residues
5	wpll	upper	insitu	Ngamba	adequate	maize-beans	rich	FYM, crop residues, green manure
6	wpll	upper	insitu	Ngamba	adequate	vegetables	rich	FYM, green manure, household wa
7	wpll	upper	insitu	Mthau mugu	adequate	banana-coffe	poor	Mulch, crop residues, green manur
8	wpll	upper	insitu	Mthau mugu	adequate	maize-beans	poor	Crop residues, green manure, inter
9	wpll	upper	insitu	Mthau mugu	adequate	vegetables	poor	FYM, green manure, household wa
10	wpll	upper	insitu	Mthau mugu	adequate	banana-coffe	rich	FYM, crop residues, green manure
11	wpll	upper	insitu	Mthau mugu	adequate	maize-beans	rich	FYM, crop residues, green manure
12	wpll	upper	insitu	Mthau mugu	adequate	vegetables	rich	FYM, green manure, household wa
13	wpll	upper	insitu	Mthau mugu	inadequate	maize-beans	poor	Crop residues, green manure, inter
14	wpll	upper	insitu	Mthau mugu	inadequate	vegetables	poor	FYM, green manure, household wa
15	wpll	upper	insitu	Mthau mugu	inadequate	maize-beans	rich	FYM, crop residues, green manure
16	wpll	upper	insitu	Mthau mugu	inadequate	vegetables	rich	FYM, green manure, household wa
17	wpll	upper	sheet flow di	Ngamba	adequate	banana-coffe	poor	Mulch, crop residues, green manur
18	wpll	upper	sheet flow di	Ngamba	adequate	maize-beans	poor	Crop residues, green manure, inter
19	wpll	upper	sheet flow di	Ngamba	adequate	vegetables	poor	FYM, green manure, household wa

Figure 6.3: Illustration of the input fields within the database and the potential management options based on the inputted information.

As already mentioned, queries can be run within the Microsoft Access database that has been developed that allow the extension officer who is using the tool to focus on the concerns raised by the farmer or community. Not all the fields shown in Figure 6.3

need to be used in the queries. The farmer may only be interested in what management options are available to them based on the crops they grow and the type of soil on their farm. Hence within the database the fields utilised would have to be the location information, soil type, cropping system and options. The capability of the outputs from this database is dependent on the purpose of its use, i.e. what the farmer wants to know.

The flowchart below (Figure 6.4) explains the application of the query function within the database. It is the extension officers who will utilise the database. An important function of the database is that the derived outputs and query results can be printed out to form quick reference tables that can be used as look-up tables for determining agricultural management options at a glance.

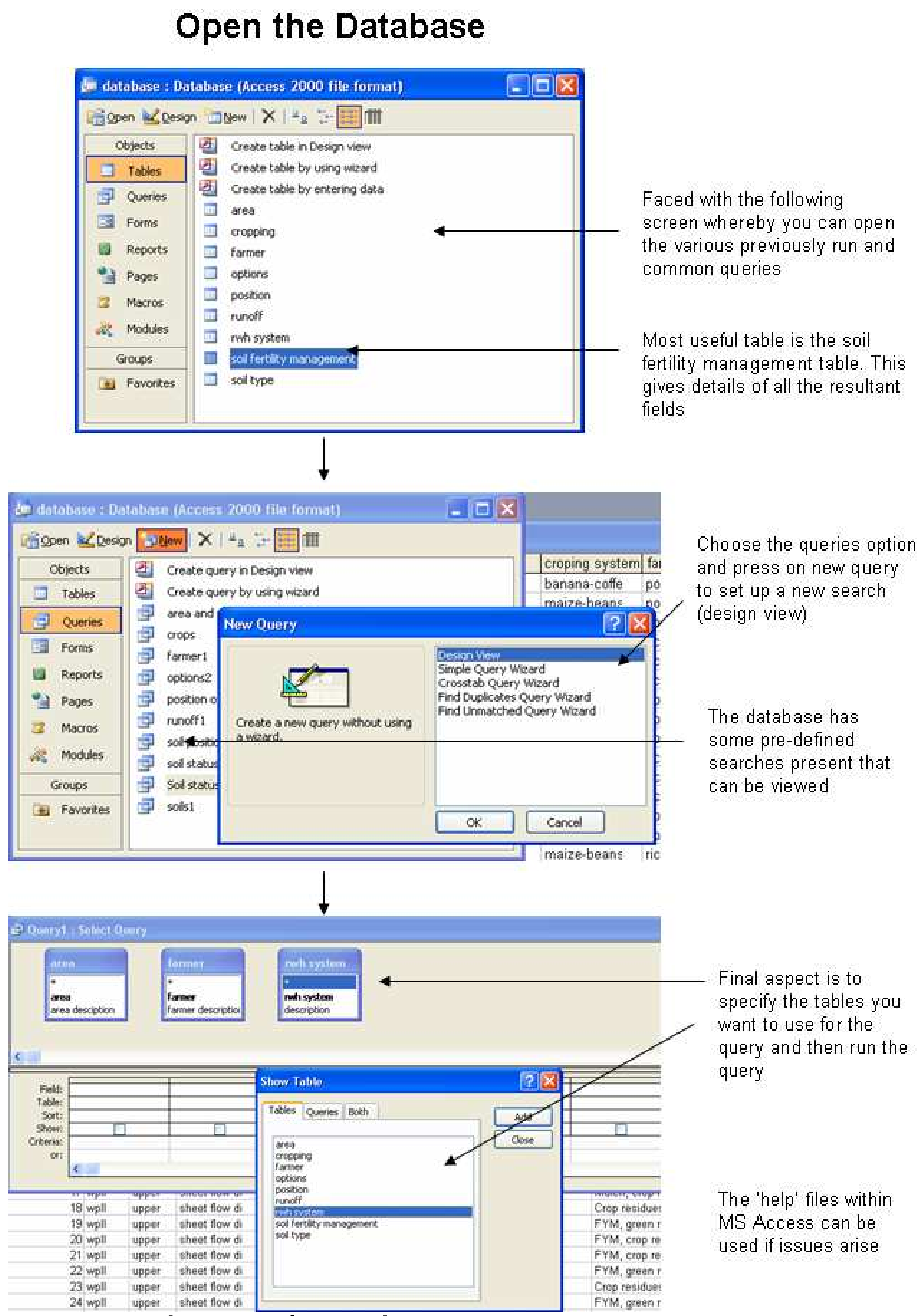


Figure 6.4: Database query functionality

6.1.3 Data Collection Spreadsheets

During the development of the Tanzanian DSS for resource management various factors and criteria have become apparent as being important for helping to understand the socio-economic situation in Tanzania, both from the point of view of the study regions and the actual community members. Criteria include Ostrom's criteria for understanding the application of CRP management regimes (Ostrom, 1990).

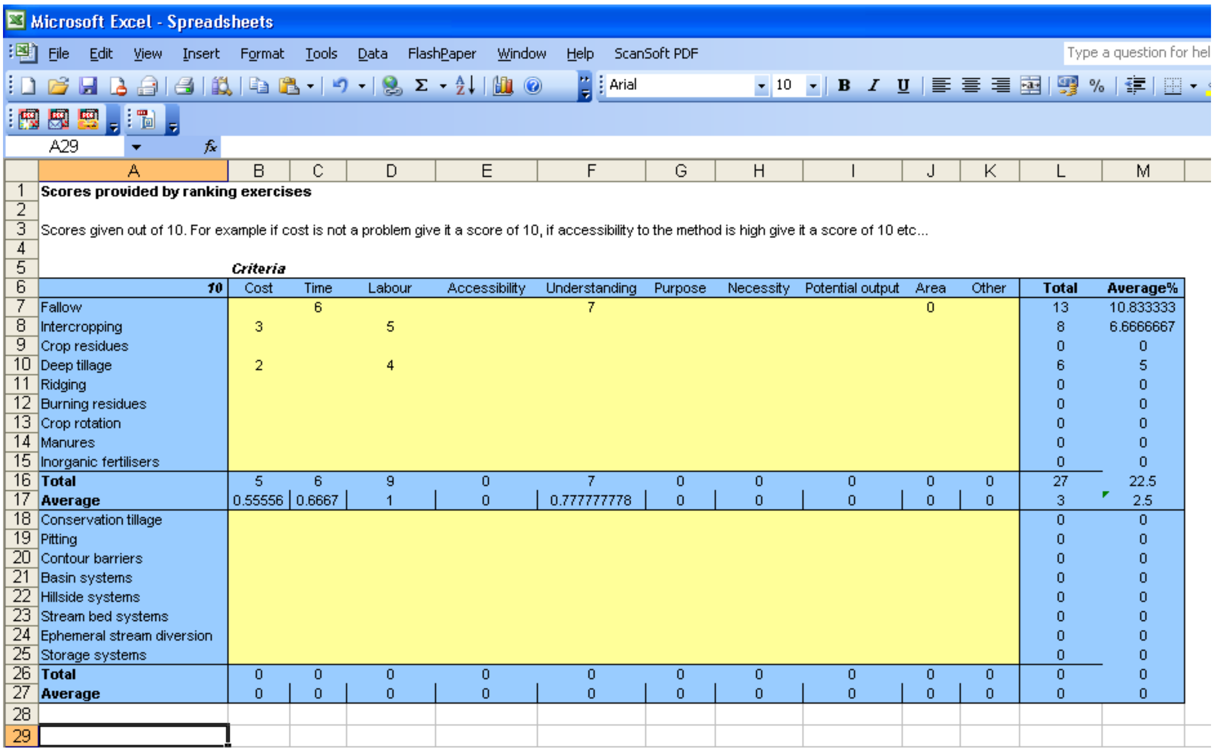
These criteria have been placed within a Microsoft Excel spreadsheet (refer to Appendix). The spreadsheet can be used as a reminder for the extension officers who are working for the communities that they should be aware of the various points covered by the criteria, and check them off as they discuss them.

Alongside socio-economic criteria and considerations, various other spreadsheets have been set up to aid the extension officers when they are learning about the members of the community and to help them understand potential wealth classifications. Also, farmer's perceptions towards different management options can be recorded via a simple scoring method.

The reason why these spreadsheets have been set up is to help the extension officers understand the community members further, and to take note of their perceptions toward potential management strategies. This sort of information is useful in classifying groups of individuals and understanding what management techniques are likely to be adopted by a specific farmer or group.

These spreadsheets are simple devices that can be used to record information ascertained through discussions with farmers, and then used as reference material to instigate further discussions and research. They do not necessarily output management strategies and should only be used and analysed by the extension officers.

The following figures illustrate the six spreadsheets that have been developed during this research. A brief description of their use is also stated.



Scores provided by ranking exercises

Scores given out of 10. For example if cost is not a problem give it a score of 10, if accessibility to the method is high give it a score of 10 etc...

	Criteria											
10	Cost	Time	Labour	Accessibility	Understanding	Purpose	Necessity	Potential output	Area	Other	**Total**	**Average%**
Fallow		6			7				0		13	10.833333
Intercropping	3		5								8	6.6666667
Crop residues											0	0
Deep tillage	2		4								6	5
Ridging											0	0
Burning residues											0	0
Crop rotation											0	0
Manures											0	0
Inorganic fertilisers											0	0
Total	5	6	9	0	7	0	0	0	0	0	27	22.5
Average	0.55556	0.6667	1	0	0.777777778	0	0	0	0	0	3	2.5
Conservation tillage											0	0
Pitting											0	0
Contour barriers											0	0
Basin systems											0	0
Hillside systems											0	0
Stream bed systems											0	0
Ephemeral stream diversion											0	0
Storage systems											0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6.5: Data Input Spreadsheet

This spreadsheet can be used by the extension officers during discussions with the farmers to determine their understanding of potential agricultural management and water management options and to see whether the approach is already in use and is understood. Human perceptions towards options are recorded through the simple scoring mechanism.

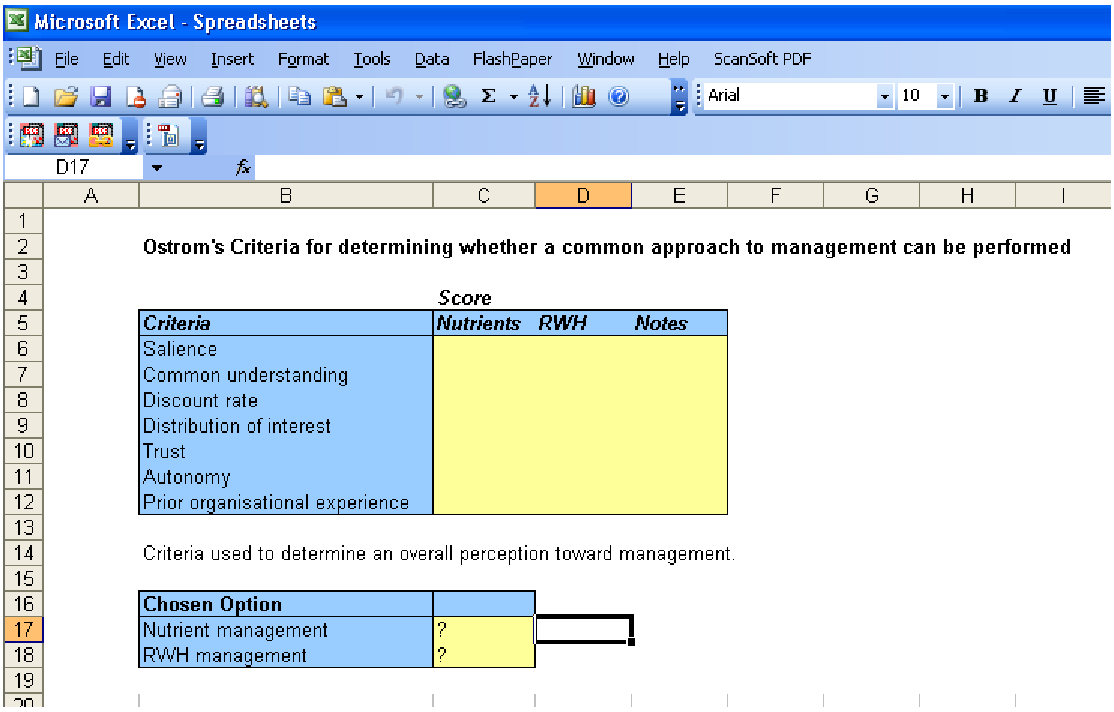
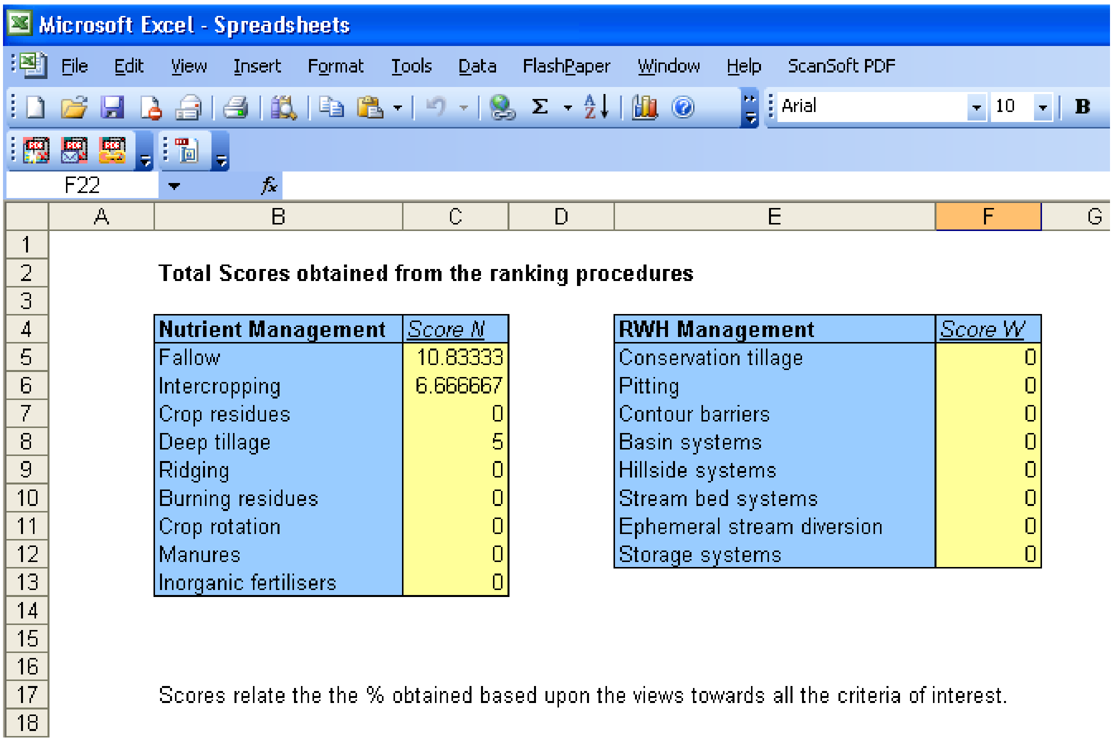


Figure 6.6: Ostrom's criteria considerations and recording of views towards the criteria

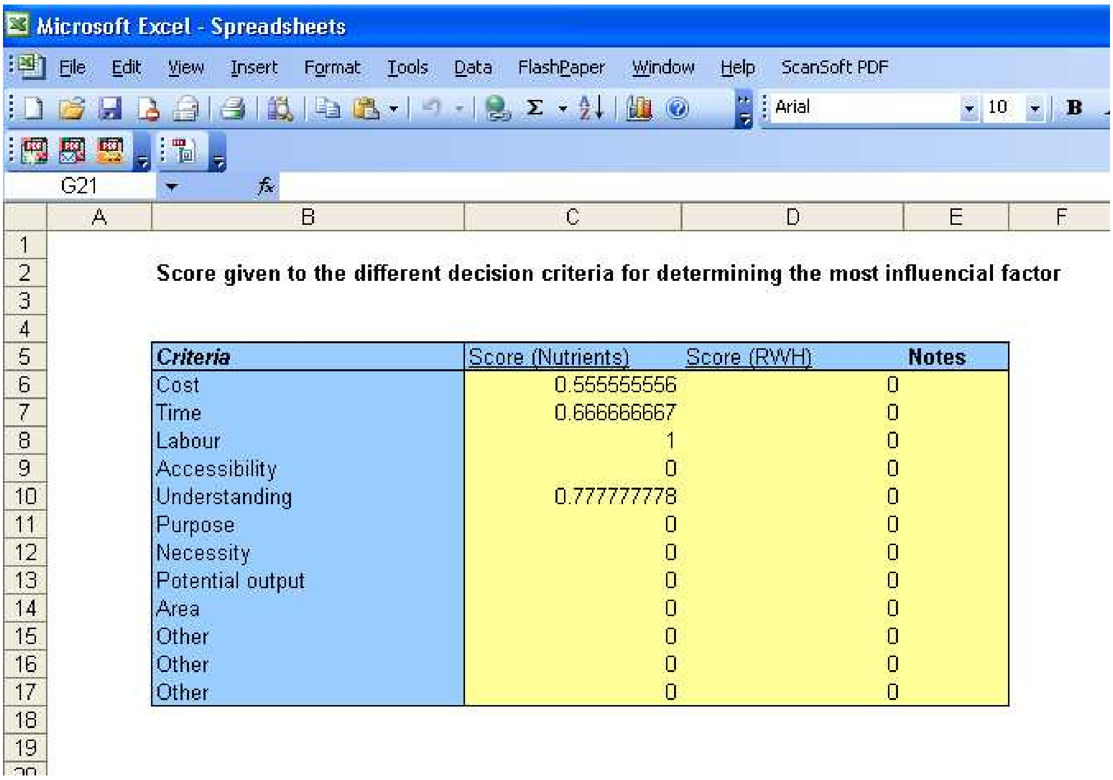
Figure 6.6 illustrates the spreadsheet whereby the criteria as described by Ostrom (1990) can be discussed. The extension officers will have an understanding of what is meant by 'salience' and 'common understanding' in relation to the nutrient or RWH management options. Within these tables they can record the view and perceptions of the farmers towards the criteria and ascertain whether there is likely to be compliance between community members for the application of CPR regimes. This information will help to give rise to a greater understanding of the social classifications and socio-economic situation within the communities being questioned.



Nutrient Management	Score N
Fallow	10.83333
Intercropping	6.666667
Crop residues	0
Deep tillage	5
Ridging	0
Burning residues	0
Crop rotation	0
Manures	0
Inorganic fertilisers	0

RWH Management	Score W
Conservation tillage	0
Pitting	0
Contour barriers	0
Basin systems	0
Hillside systems	0
Stream bed systems	0
Ephemeral stream diversion	0
Storage systems	0

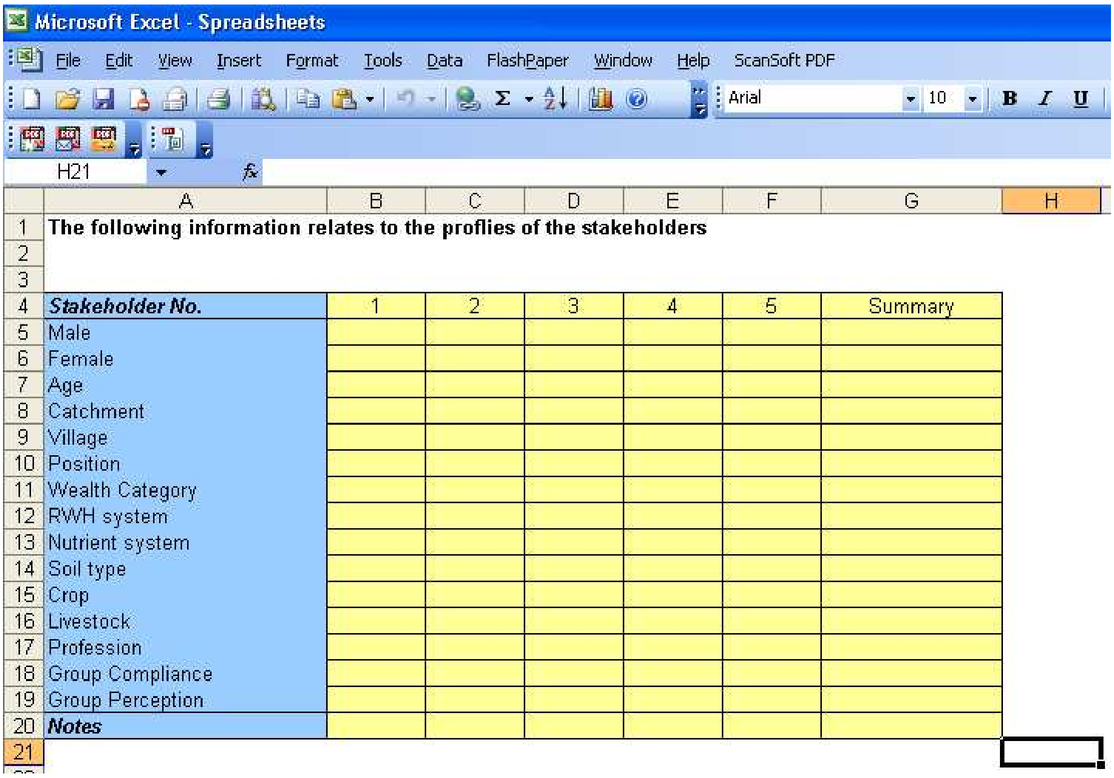
Figure 6.7: Total Score Spreadsheet. This spreadsheet links with the first spreadsheet and houses the total scores specified by the farmers for their perceptions towards different nutrient and water management techniques.



Score given to the different decision criteria for determining the most influencial factor

Criteria	Score (Nutrients)	Score (RWH)	Notes
Cost	0.555555556	0	
Time	0.666666667	0	
Labour	1	0	
Accessibility	0	0	
Understanding	0.777777778	0	
Purpose	0	0	
Necessity	0	0	
Potential output	0	0	
Area	0	0	
Other	0	0	
Other	0	0	
Other	0	0	

Figure 6.8: Total Scores Spreadsheet. This spreadsheet also links with the first spreadsheet and is used to determine which decision criteria are the most important to the farmers.

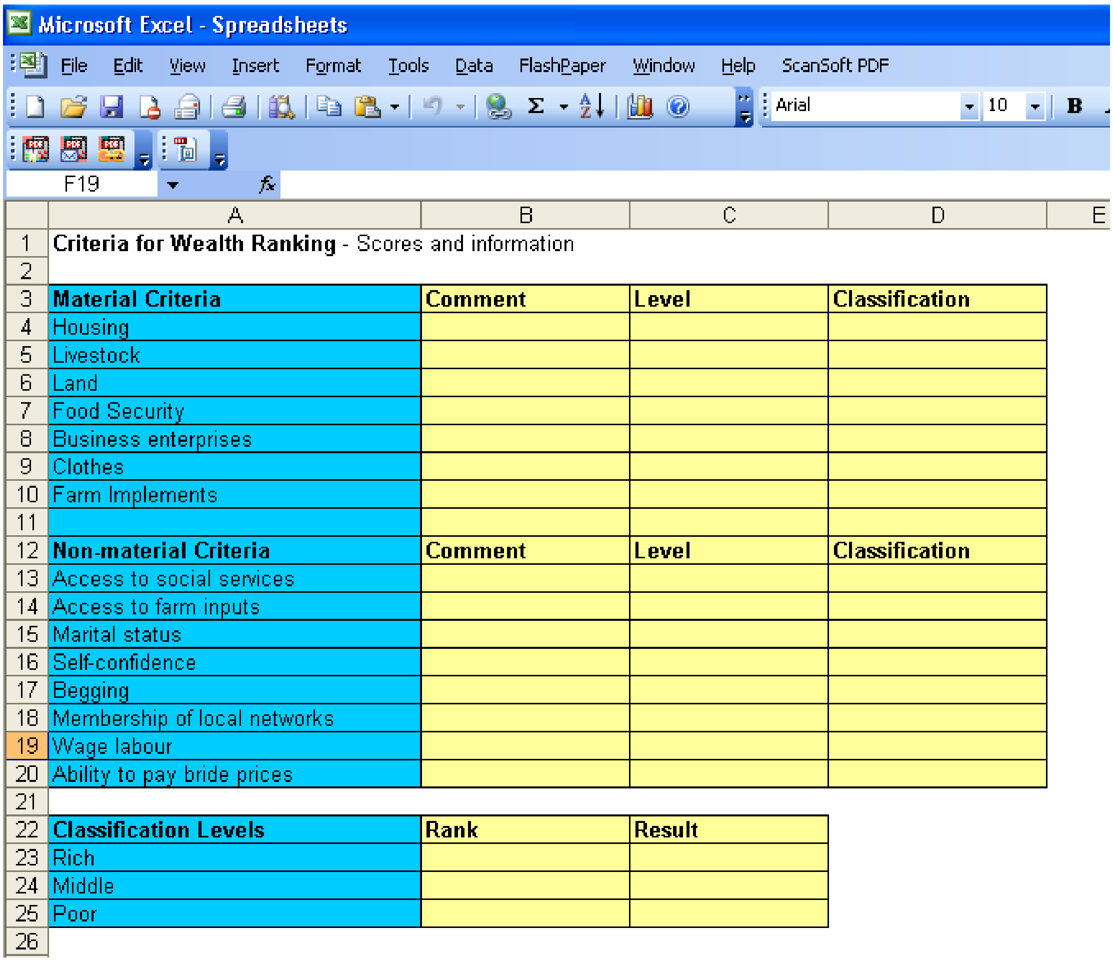


The following information relates to the proflies of the stakeholders

Stakeholder No.	1	2	3	4	5	Summary
Male						
Female						
Age						
Catchment						
Village						
Position						
Wealth Category						
RWH system						
Nutrient system						
Soil type						
Crop						
Livestock						
Profession						
Group Compliance						
Group Perception						
Notes						

Figure 6.9: Profiling of stakeholders

The spreadsheet shown in Figure 6.9 can be used to record the details of the community members who are being questioned during the research process, for example within focus groups. The views of the group being questioned are recorded and it is possible to see whether there is compliance between the group. In this example, five people are being questioned. Compliance between members is assumed if the members of the group give similar (or the same) scores and information for the criteria being discussed.



	A	B	C	D
1	**Criteria for Wealth Ranking** - Scores and information			
2				
3	**Material Criteria**	**Comment**	**Level**	**Classification**
4	Housing			
5	Livestock			
6	Land			
7	Food Security			
8	Business enterprises			
9	Clothes			
10	Farm Implements			
11				
12	**Non-material Criteria**	**Comment**	**Level**	**Classification**
13	Access to social services			
14	Access to farm inputs			
15	Marital status			
16	Self-confidence			
17	Begging			
18	Membership of local networks			
19	Wage labour			
20	Ability to pay bride prices			
21				
22	**Classification Levels**	**Rank**	**Result**	
23	Rich			
24	Middle			
25	Poor			
26				

Figure 6.10: Criteria for wealth ranking

Figure 6.10 details the spreadsheet that contains the criteria used for determining the wealth classification of the farmers. It is split into material and non-material criteria, each of which needs to be discussed and scored. Examples of comments related to these criteria have been expressed within Chapters 4 and 5. This spreadsheet allows the extension officer to record the status of different individuals in terms of each criterion to help ascertain their wealth status.

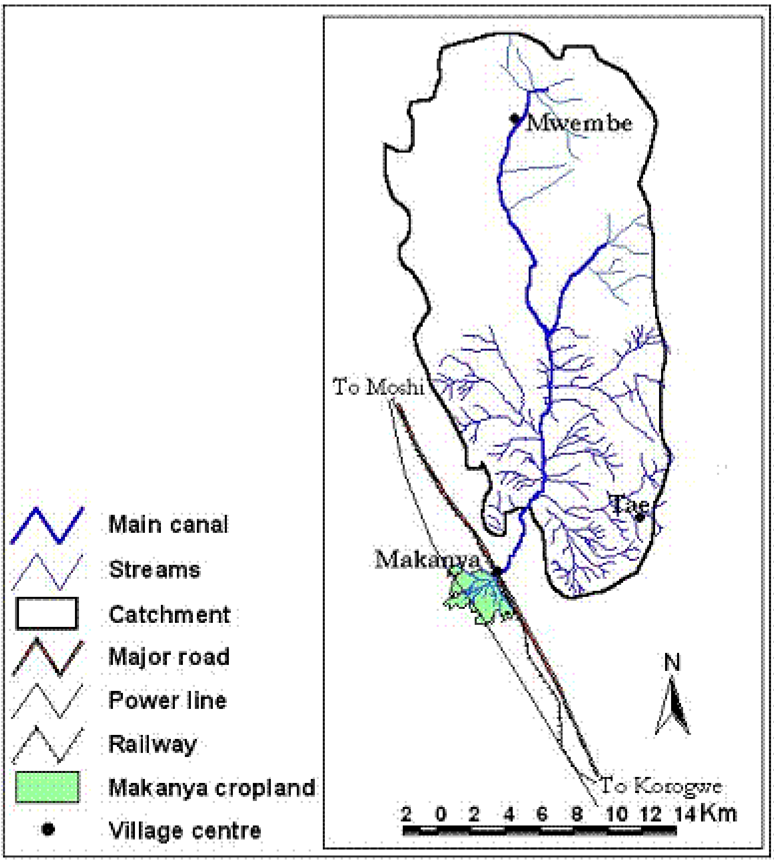
As with the database and DSS, the spreadsheets need to be loaded onto a computer and it is the extension officers who will have access to them. The spreadsheets can be printed out and taken into the field for recording purposes. They can be used for instigating discussions between the farmers and extension officers as they highlight criteria and points of interest for the determination of suitable management options.

6.1.4 Geographical Information Maps

Another output from this research was the production of various GIS maps to help represent the study regions. The type of information displayed on these maps relates to local infrastructure, land classifications, cropping suitability and sustainability.

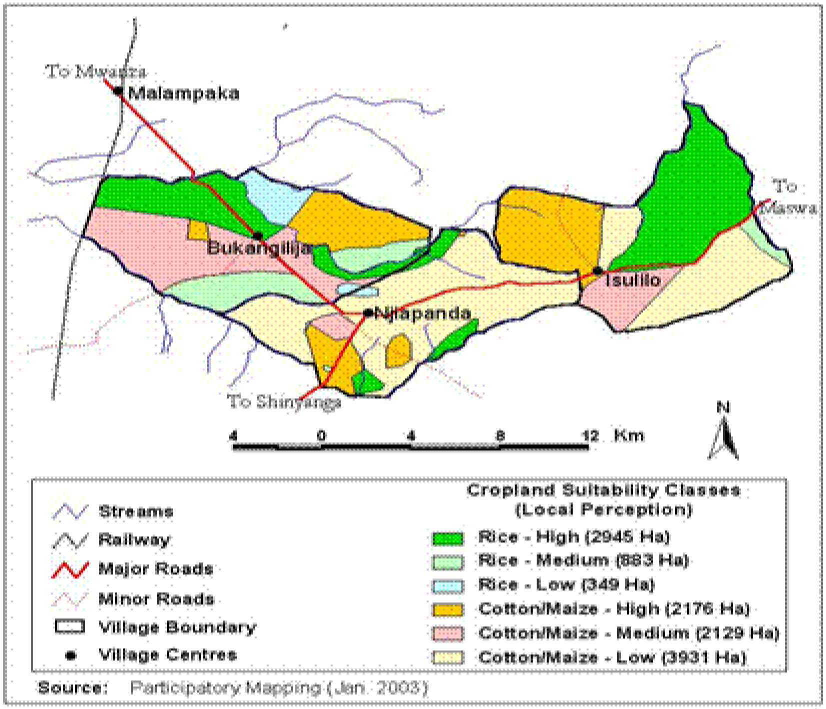
These maps are a good visual representation of the study regions and help to bring an alternative approach to viewing and recording land characteristics. The maps help to add focus to the data collection carried out by the extension officers and give direction to where observations could be made. For example, if there is an interest in the rice growing regions of Tanzania, these areas can be pin pointed on the maps and subsequently the extension officers can travel to these areas to carry out their research. The maps also provide a useful overview of the distribution and topography of different crops and allow decisions to be considered on a regional scale. From the point of view of the farmers, the maps can be used as a visual aid to help them see and understand their locality in relation to resources and infrastructure.

Figure 6.11 below illustrates two GIS maps that were produced by the team in Tanzania during this research project. They show different attributes, such as local infrastructure and potential cropping suitability classes. They also highlight the different ways in which GIS maps can show results, for example the blocking in of sections (cropping areas) or the use of simple outlines (catchment areas). These maps are a useful visual aid that the extension officers can utilise and share with the community when highlighting different management options.



Map One

This map illustrates the villages and infrastructure within the WPLL. The key on the left details the objects that can be viewed. Plus there is a scale to represent distances.



Map Two

This map shows the cropping suitability classes within the villages in the district of Maswa. Infrastructure such as roads and streams are also highlighted.

Figure 6.11: Example GIS maps

6.2 Combining the research products

The four research outputs described above can be utilised as stand alone products to aid in the management of water and nutrient resources in Tanzania. However, they can also be combined, such that two or more systems may complement each other to help enhance the research outcomes.

The Tanzanian DSS can be used in conjunction with the database and the developed spreadsheets, in order to understand the inputs given to the DSS and the extrapolated management options. One of the spreadsheets contains the criteria that are used within the wealth classification section of the DSS. Therefore the results can be recorded within the spreadsheet and subsequently transferred to the DSS. The database gives rise to agricultural management options that are associated with different cropping practices and water regimes. Therefore, from the DSS outputs it is possible to determine the water level and the crops being grown (rice or maize). This information can be used within a query in the database and the potential agricultural management options realised.

The GIS maps link with the other developed tools by acting as an overview for the distribution and topography of the different crops. Location information can be determined alongside the environmental conditions prior to any participatory questioning being carried out with the farmers and communities.

These links between the developed tools are not physically present, such that the database and spreadsheets do not feed directly into the DSS at ‘the press of a button’. This, however, is an area that could be tackled in the future development of the Tanzanian DSS and its additional tools. The links between tools have to be made by those using them. Also all the tools use Microsoft software, hence MS compatibility is an issue that needs to be considered when using the tools. All of the developed tools can be seen as a method for instigating discussions between community members and extension officers to help in understanding and improving agricultural management and resource allocation.

Figure 6.12 illustrates how the outcomes from this research can link together. Alongside the diagram is a table that details how the different products link to each other.

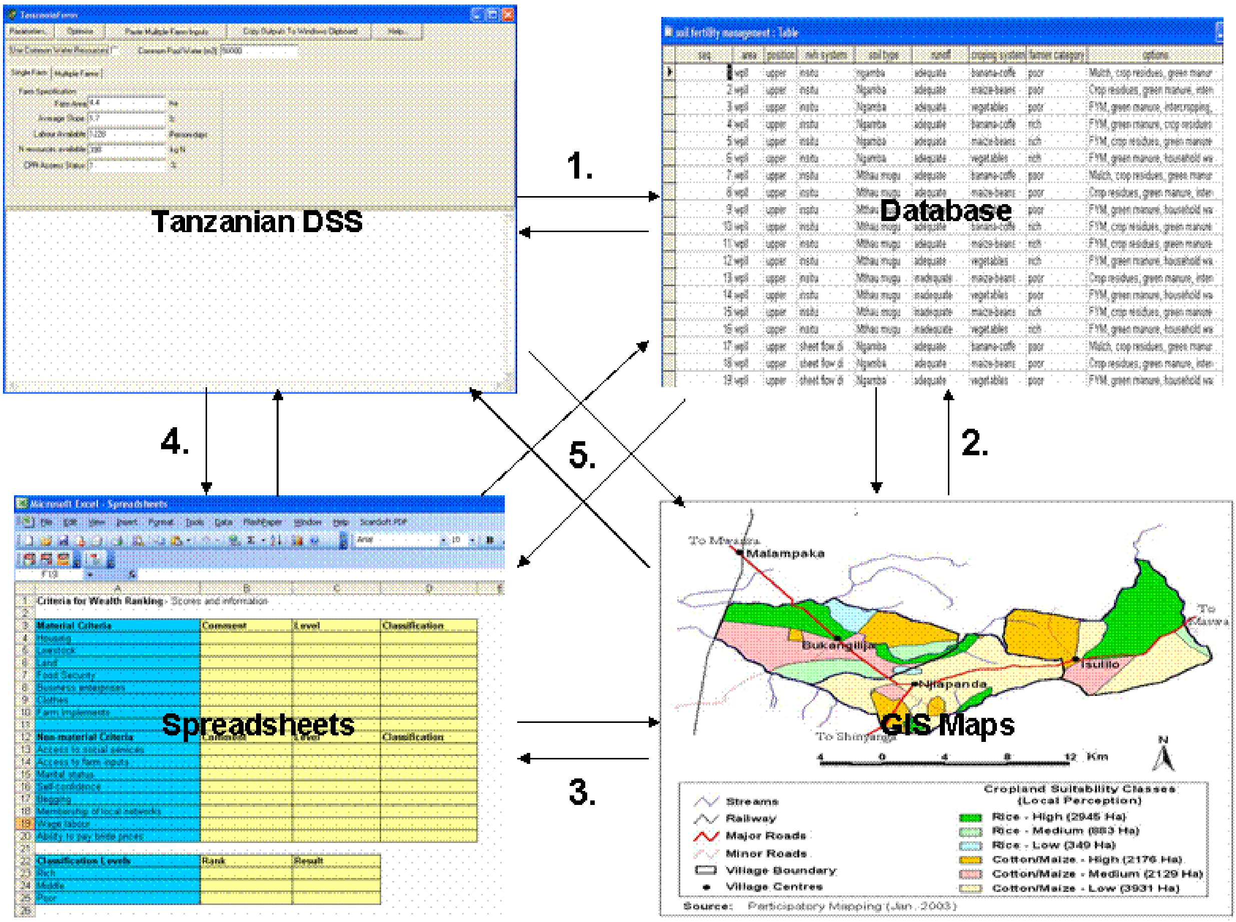


Figure 6.12: Combining the four research outcomes.

Table 6.2 below details how the research products can be combined. This combination does not have to just be between two products but can be between 3 or all 4 products. Each developed system is related.

Point	Details of links
1	The link between the DSS and the database is formed when understanding what management options are feasible for the farmers based on their location information. The DSS takes topographic information and outputs results related to water allocation. Within the database there is information about RWH regimes and water levels. Therefore from the determination of the water level from the DSS, the database can be searched to ascertain the type of management option available based on the stipulated water level and location information. Also, the crops that can be grown can be determined.
2	The link between the database and the maps is more a visual one in that the maps help the extension officer to picture the villages that they are working with and carrying out searches within the database for.
3	The maps and the spreadsheets link in the same fashion as with the database, such that the maps help to give a visual representation of the study regions. During the application of the spreadsheets and discussions with the farmers the maps could be shown to help the farmers to understand there location further.
4	The link between the spreadsheets and the DSS are more pronounced. Such that the scores that are recorded for understanding the views towards wealth ranking (Figure 6.10) could be used within the section of the DSS whereby the extension officer inputs the farmers' perception of wealth. Spreadsheets such as those related to Ostrom's criteria link with the DSS as they will help the extension officer to determine whether the DSS should be applied at a single farm level or multiple farm level. This is one of the decisions highlighted in the flowchart (Figure 6.2).
5	There are links between the database and the spreadsheets as they both utilise similar data sets and criteria information. The links between the maps and the DSS are primarily associated with using the maps as a visual representation of the study region to express where the outputs from the DSS can be applied. For example areas with similar environmental and physical conditions can be located on the map, and therefore it is likely that the results from the DSS could be extrapolated to these areas with the same conditions.
Additions	It is possible to utilise the functions of all the research products in conjunction with each other to enhance the outputs derived from the DSS and give greater weighting to the management options expressed, such that the results are more reliable. This comes about from greater participation and enhanced communication between the extension officers and the farmers and community members when using the various research outputs. It is important to check that all data being supplied is accurate, as the outputs from the systems are only as good as the inputs provided.

Table 6.2: Links between the different research products

6.3 Systems Development

For the development, utilisation and extrapolation of the products of this research seven phases as outlined by Taylor (2001) can be used. These are listed in Table 6.3.

The Phases of Decision Support System Development
1. Definition Phase: Precisely define the problem to be solved, its magnitude and who will work on it
2. Requirements Phase: Develop a detailed description of exactly what the development effort will produce. Gather all the relevant information and put it into a requirements document and get client agreement.
3. Evaluation Phase: Determine exactly how you will meet the requirement. What tools will you use? How will you deploy your development team? Determine time and budget constraints.
4. Design Phase: Create a database model and the design a database and database application that satisfy the terms of the requirements document.
5. Implementation Phase: Build the application and maintain documentation of all processes during development.
6. Final Documentation and Testing Phase: Test the database and application thoroughly, trying out every conceivable input and condition. Primarily try and 'break' the system. Determine where the system falls over and document and review the issues.
7. Maintenance Phase: Fix any bugs that arose during testing. Provide updates and enhancements to the system on a rotational basis.

Table 6.3: The seven phases of decision support system development (Taylor, 2001)

Alongside these phases, during the development of the tools the researcher needs to be aware of three aspects during the research process. These are:

- The collection of information and data
- The proposed application of any designed/developed tool
- The dissemination and interpretation of results ascertained from the developed tools

Ensuring that these points are thought about during the research process will help to enhance the potential of the final product(s). The reasoning behind this is that the research will remained focused on the end product and those working on the development of the tools (for example the DSS) will have a clear understanding of its purpose and direction, hence feasible solutions should be derived.

The three points stated above are of particular importance to the extension officers who are utilising the developed tools as well. They need to be aware of the data that they are collecting to ensure that it is relevant to the question that they are trying to answer, and that it is suitable for the tool they are using. It is also important that the correct tool is used when collecting the data. Hence knowledge of how to apply and use the developed tools (as stated in section 6.1 above) is of utmost importance to the extension officers. These step-by-step guides and process flowcharts will help to ensure that the tools are properly used and understood. The extension officers are the key focal point when it comes to disseminating the outputs from the developed tools. It is their role to discuss the results with the end beneficiaries of the systems – the farmers and communities in the study villages. They need to make sure that the results are easy to understand and can clearly be verbally expressed to the end beneficiaries. Also, any visual representations and reference material that should be expressed to the farmers should be a in a clear and understandable format. These decisions are at the discretion of the extension officers.

The last point that should be re-iterated (as already discussed within chapter 3) is that with any system that is developed it is important to apply some form of follow-up work and maintenance of the developed systems and tools. This maintenance is likely to occur on a 3 to 6 month basis and is when the tools get reviewed and any required amendments and updates are made to them. For example, in the case of the tools developed for resource management in Tanzania, potential updates may include the addition of more records to the agricultural management database, enhancement of the spreadsheets, the development of new GIS maps that show different attributes, and the re-assessment of the relationships that are used within the mathematical model in the Tanzanian DSS. Once again these updates are at the discretion of the developers of the tools and those that are using them most often (extension officers) as they are likely to be able to highlight where problems and flaws in the systems occur.

6.4 Summary

The information expressed above helps to demonstrate how the tools that have been developed during this research project should be applied within the field – i.e. in the context of agricultural and resource management in Tanzania. Particular focus is on the interaction between the extension officers (those who use the tools) and the farmers/communities in the villages (those who benefit from the outcomes of the tools and provide the questions and data for the initiation and application of tools). This interaction is of the utmost importance as it will help to ensure the acquirement of feasible solutions for the tools and enhance the dissemination of information determined from using the tools. Communication between the end users of the system and the end beneficiaries during the development and utilisation of the tools as well as the extrapolation of results must be sustained throughout the research proceedings.

Chapter Seven:

DISCUSSION

7.0 Introduction

This chapter reiterates the objectives and discusses how they have been achieved. Challenges encountered during the research are identified and solutions to them examined. Potential improvements and future research priorities will demonstrate how this study has contributed to DSS development.

This research demonstrates the building blocks for future developments in agricultural management DSSs. Many opportunities exist where computer systems can be used to help improve management processes and aid agricultural practices (Matthews *et al.*, 2002). Computer systems offer powerful technical tools for enhancing management. However, using intrinsic knowledge and understanding of the individuals in a community of management practices is often the most useful approach to take. A combination of the technological and human aspects to agricultural management should be seen as a step in the right direction for developing sound management systems.

The concept of combining the technological and human aspects to management – by integrating the quantitative and qualitative data types – has been a fundamental focus of this research, and has been fundamental to the development of the Tanzanian DSS.

7.1 Research Objectives

As stated in Chapter One, the objectives of this research were to (1) Develop a DSS that incorporates quantitative and qualitative data to aid in the management of RWH in Tanzania to help enhance sustainability of livelihoods for the farmers, and (2) Outline where experiences gained in the development of the Tanzanian DSS might contribute to a generic strategy/approach for the development of DSSs.

The key points attributed to both of these objectives are now discussed in relation to the information described in the previous chapters. Each chapter will be taken in turn and the key points from the research re-iterated. Limitations to the research shall also be stated and discussed in relation to how they could be overcome.

7.2 The Study

The research demonstrated within this study and the subsequent development of the Tanzanian DSS forms a small part of a bigger research programme on soil-water management that was started in 1991 by Faculty of Agriculture of Sokoine University of Agriculture in Tanzania. The main purpose of the programme was to develop, test and provide appropriate and socio-economically viable management interventions for optimising the capture and utilisation of rainfall – e.g. Rainwater Harvesting "RWH" in semi-arid areas of Tanzania (Mahoo *et al*, 1999; Mzirai and Kajiru, Personal Communication, 2003).

Following many field-based activities, it became apparent that there was a need to develop support systems to assist extension staff and others to plan, design and implement RWH systems. It was agreed that the use of computers could assist in the development and promotion of effective approaches to RWH by quantitatively integrating water and nutrient issues at the farm level. This brought about the decision to develop the Tanzanian DSS for agricultural management of water and nutrient resources.

The Tanzanian DSS is concerned with the application of RWH techniques. The farmers in Tanzania are already applying RWH techniques, however in many cases they are not being utilised correctly. The DSS gives details of how water resources can be distributed for the growth of rice and maize, and also helps to instigate discussions between farmers and extension officers as to which RWH technique may be of benefit to them, for improving their agricultural productivity. Various RWH options are available which have been outlined in Chapter Two. RWH techniques offer a way of conserving and distributing water resources obtained from sporadic rainfall events more successfully in terms of crop productivity and sustainability. The Tanzanian DSS and the interaction between the extension officers and farmers aims to help improve awareness of RWH management options and demonstrate how approaches such as conservation tillage, pitting, contour barriers and charco-dams could be of benefit for enhancing agricultural performance – both for crops and livestock.

7.3 Systems development, analysis and modelling

Before the Tanzanian DSS could be developed it was necessary to have a clear understanding of what the system hoped to achieve and who the potential users and beneficiaries of the system would be.

The potential users and beneficiaries of the system were identified as:

- **End users –** these are the extension officers and researchers in the study regions who will work with the beneficiaries of the DSS to utilise the functions within the system.
- **Test subjects –** these are the farmers in the study regions for whom the system is being developed and the research is being carried out.
- **Beneficiaries –** these are the farmers of different social status within the study regions who will ultimately benefit from the system(s) being developed.

The aim of the Tanzanian DSS was to complement the intrinsic knowledge of the Tanzanian farmers to help enhance or maintain the sustainability of their livelihoods. Through participatory analysis, the DSS is also to be used as a tool to question existing practices and identify new approaches towards water and nutrient management.

Various strategies for the development of DSSs and agricultural models exist such as those demonstrated by Marakas (2002) in chapter three. All of these approaches share similar qualities in that they have a starting point for development, which usually involves the understanding of system that is to be developed and the specifying of objectives. This is subsequently followed by the research and development phases, culminating in the extrapolation of the developed system. Kebreab (2000) describes a series of points that should be followed when undertaking computer modelling research, these points can be seen in Table 3.1. These points can be further condensed as demonstrated by Taylor (2001) who describes '7 Phases for the development of decisions support systems'. The work of Kebreab and Taylor show how there are many similarities between approaches to DSS development, hence it is up to the individual as to which avenues to pursue.

The development strategy for the Tanzanian DSS has incorporated the work outlined in Chapter 3, with the main focus being on the phases of development described by Stroosnijder (2001). Stroosnijder (2001) describes the three fundamental phases for systems development which have been incorporated for this research, alongside the work of Sprague *et al* (1996) that focuses on the DDM paradigm. The three phases are:

1. Descriptive – whereby the objectives of the system to be developed are outlined and research is carried out in order to understand the potential users of the system and to understand any existing conditions or situations affiliated to the study region or participants.
2. Explorative – whereby analysis of existing systems is carried out which leads onto the building of detailed requirements specifications for the newly proposed solution. The data is collected and stored in a suitable database and the tools for developing the model are chosen and instigated.
3. Planning – whereby the system is designed, developed and subsequently tested in the field. This phase culminates in the implementation of the developed system in the field and should be followed by a review process to assess the continued application of the developed system.

It is important to have a framework to follow when developing DSSs as they help to give direction to the development process. "If a picture is worth a thousand words, a framework is worth a thousand pictures". This statement is fundamentally true. Without a sound framework it would be impossible to develop a successful solution to a stated problem. Not all frameworks are successful – this is dependent upon the user of the proposed framework.

The DSS was completed and subsequently disseminated to the team in Tanzania where the extension officers have had access to its capabilities and processing. On attaining feedback on the system, further developments and enhancements can be made. Reviews and checks on the system should be carried out also. It was also important to specify to the end users that the Tanzanian DSS only extrapolates *potential* management options. There is still an element of risk with the application of the specified allocation of resource that is obtained from the DSS, as with any biological system, it is difficult to fully predict its functionality and lifecycle.

Frameworks add structure to the problem solving and decision-making processes that take place during systems development. Both quantitative and qualitative data are important for the production of DSSs that are suitable for solving management issues. This point shall now be discussed.

7.4 Quantitative and qualitative research

The fundamental aspect for the development of the Tanzanian DSS was the integration of quantitative (numerical) and qualitative (social) data types. The majority of models and DSSs only utilise one data type (Moulin, 1994; Matthews *et al.*, 2002). By combining data types, a new level of outputs can be achieved – one that takes into consideration the end users opinions as well as the physical/numerical data. The importance of the data for the development of the Tanzanian DSS shall now be discussed.

In summary, the predominant forms of data capture were through existing models that were able to generate data sets that covered a 30-year period for the study regions in Tanzania. The model used was PT. The data extrapolated from this model were analysed against the limited field data collected. Regression analyses were performed to help ensure agreement between predicted and expected yield performances based upon varying levels of water and nutrients. These numerical data were then utilised for building the mathematical relationships between water/nutrients and their effects on crop growth. The derived relationships were cross-referenced with those found in the literature for resource capture and utilisation (Loomis *et al*, 1998; Meinzen-Dick *et al*, 2002).

From the data requirements (Table 7.1) it was possible to determine the parameters that were required for building the Tanzanian DSS. Listing the required parameters in a table helped to add focus to the data gathering process. This is one area that is also highlighted within the strategy for DSS development – the Requirements Specification phase. Principally, the main numerical data that were collected were related to levels of rainwater and nutrient (manure) captured and applied, and their underlying effect on the growth of maize and rice.

Basic Information	**Types of Information**
Basic Maps	- Topography - Settlements - Communication systems - Administrative boundaries
Climatic	- Rainfall, temperature, light intensity, day length, humidity and wind
Land	- Soil (description, classification, mapping, suitability) - Topography (slope classes, physiographic units) - Land units - Land ownership records
Water resources	- Surface water e.g. rivers and flash floods - Subsurface water (extent, yield and quality of aquifers)
Land covers and land use	- Land cover - Land use - Environmental requirements of crops
Population (number and location)	- Human - Farm animals - Wildlife
Social information	- Group (description and classification) - Objectives (land users, community, government) - Resources and constraints
Economic data	- Input costs - Sales price - Transport costs
Physical infrastructure	- Markets and processing plants - Road and railways - Houses - Water reservoir
Institution and legal aspects	- Information on relevant institutions and their responsibilities - Documents of laws applying to relevant aspects of land

Table 7.1: Requirements specification information for the development of new management systems (Hatibu, 2000)

As with the majority of models and DSSs, the numerical data collected were manipulated through the development of mathematical relationships to simulate the actual process being modelled. Where the Tanzanian model differs from the standard simulation models (Matthews *et al*, 2002) is that it has incorporated qualitative data borne from social studies of the farmers in the study regions. The collected data have been collated via means of numerical scoring to help integrate them into the development of the Tanzanian DSS.

Table 4.5 illustrates some differences between quantitative and qualitative research – adapted from Bryman (2000). The eight points listed highlight where the two research traditions diverge. Figure 4.4 expresses how the importance of having a structured process flow for the collection of both types of data is of utmost importance (Tufte, 2004).

In planning for RWH systems, it is not enough to just consider the technical and numerical aspects but also the socio-economic environment (Baland *et al,* 1996).

An understanding of the social constraints that influence the decision-making processes involved in partitioning of resources has been an important addition to the development of the Tanzanian DSS. It has helped to add focus to the system and to make it user-friendly. This was achieved via constant communication with the extension officers in Tanzania and by following a rigid development structure outlined by the requirements of the system at the onset of the research. This is ultimately a very important aspect of system development, ensuring the final product is user-friendly and aimed at the correct audience level, and forms an important part of the 'planning phase' illustrated by Figure 3.11 for DSS development.

For the production of the Tanzanian DSS it was important to research and utilise both numerical (quantitative) and social (qualitative) data. It had been observed that social factors were influencing the partitioning of the water/nutrient resource (Kajiru, Personal Communication, 2004), and this needed to be accounted for in the simulation model that had been developed through numerical analysis of crop yield responses and data. This adoption of both types of data allowed for a more focused DSS to be produced that could be applied at either the community level or single farmer level. Both options proved beneficial for the study regions – Maswa and WPLL.

An awareness of the socio-economic environment and how it influences the direction of the system being developed is fundamental in producing a sound end product. In the case of the Tanzanian DSS the focus was upon RWH.

7.5 Application of information and development of the Tanzanian DSS

The development of the Tanzanian DSS comprised two phases. Phase one focused on developing mathematical relationships by utilising data and manipulating this within Microsoft Excel. Phase two integrated the derived relationships into the Delphi designed model. The DSS gives options related to the optimal application method of the two available resources (water and nutrients). These options give the farmer(s) a guide related to the potential yields they could receive by applying their resources in the way the DSS stipulates. These are however only options and it is the farmer's choice as to whether they wish to adopt the specified approach. This decision will be aided by discussions held with extension officers and village elders to determine the best strategy to adopt.

The focus of the Tanzanian DSS is on the management of water and nutrient resources at a single farm level or multiple farm level. The DSS makes use of numerical inputs based around total levels of water (rainfall and additional water added) and nutrient application (level of nitrogen added). These inputs are used in a simple mathematical relationship to determine the potential yields of rice and/or maize. A novel addition for the development of the Tanzanian DSS was to include wealth ranking criteria as a variable that would influence the allocation of resources for the maintenance of livelihoods. Areas of interest included; number of livestock owned, type of housing and ability to pay for labour. Knowledge of this sort will influence the allocation of additional resources, such that richer farmers will be able to afford, for example, additional inorganic fertilisers. It also affects whether a common pool resource (CPR) regime can be adopted, i.e. how likely is it that the farmers will work as a community and share the resources available to them so all get some benefit? This is a question that has to be asked and discussed amongst the farmers and village elders, alongside the extension officers who are utilising the Tanzanian DSS.

An awareness of social information has led to the recognition that social factors influencing decision-making needed to be incorporated within the development of the

Tanzanian DSS. Fundamentally two areas were looked into with regard to the development of the Tanzanian DSS

1. The development of ranking criteria that influence the partitioning of resource (social factors)
2. The application of CPR strategies and theories

Ranking criteria were determined through observation and the holding of focus groups in the Tanzanian villages. Discussions were held with the village elders to help determine which factors influence the partitioning of the available resources. Primarily an understanding of what factors influenced social status were documented. Table 4.10 describes the criteria that were determined from this research. Particular interest focused on livestock ownership, food security strategies, labour availability and agricultural practices. This research concluded that the majority of farmers in the study catchments fell under the category of 'middle' wealth status (70%). These types of farmers have the ability to hire labour and may own up to nine heads of cattle. Their houses tend to be built with bricks however are not well furnished like the richer farmers houses. They will also own land to enable sufficient growth of crops for the sustainability of their livelihoods.

These criteria were subsequently utilised within the model base and dialog system for the development of the Tanzanian DSS. This is demonstrated within Chapter 5 Equation 12. Each social factor is associated with a wealth index (SEf) (1-5) and with a weighting factor (W_{SEf}), which establishes the importance of each factor on the final social hierarchy index. Farmers are asked to score each social factor in relation to how important they feel it is when deciding upon an agricultural technique to apply. The higher the score the more important the factor is for the decision making process. This approach helps to incorporate human perception towards management strategies. The development of the social hierarchy index illustrates how social data (qualitative) can be incorporated within the development of DSSs in a quantitative fashion.

From the onset of this research there was an interest in understanding how CPR strategies could be incorporated within the development of the DSS. The Tanzanian DSS tackles the issue of CPR via the application of the social hierarchy index. Also within the DSS there is the option to choose a community based water resource and apply the system at either an individual or community level. The Excel spreadsheets demonstrated in Chapter 6 highlight the principle areas of interest with regard to CPR as does Table 5.2 (Ostrom, 1990). Criteria are listed that allow the user of the DSS to decide whether or not it is advisable for a community to adopt a particular management regime.

Delphi was the programming language used for the development of the DSS. Chapter 3 discusses the reasons why this language was used for the Tanzanian DSS, the main reason being that extensive knowledge of the language was already present amongst the system developers. It can be asked 'was this the correct programming language/approach to use for the development of the Tanzanian DSS'? At the time of development, the use of Delphi was justified as it possessed the necessary functions that were required for the development of the Tanzanian DSS. Also the language was widely understood by the developers based in Nottingham and Tanzania. More recent approaches to systems development have seen an increased use in software such as MySQL for the development of databases and the application of FLASH Macromedia tools for linking these databases with a website environment. This is an area of systems development that could be looked into in the future for the development of DSSs as it may help to make the tools more widely available via the use of the Internet. However this depends on the research area, the design of the end product and the purpose of the DSS.

7.6 System dissemination and application

As discussed in Chapter 3 and detailed in the phases of systems development as outlined by Kebreab (2000), Taylor (2001) and Strosnjider (2001), a fundamental aspect when developing a DSS is to have an understanding of how the end product will be extrapolated to the end users and beneficiaries. Chapter 6 details the importance, dissemination and utilisation of the Tanzanian DSS. The end users of the tool are re-iterated, these being the extension officers based in the extension offices in the study regions. The extension officers are the people who will use the DSS, input the data provided by the farmers, and subsequently discuss any potential management options with the farmers in question. Therefore it can be concluded that the end beneficiaries are the farmers for whom the DSS has been developed.

Chapter 6 expresses details related to all the products that were developed during this study. This includes the Tanzanian DSS, but also the various spreadsheets that can be used to house information that is determined during focus group discussions with farmers in the study regions. Plus the agricultural management database is expressed further. This is a simple relational database that allows the extension officers to choose agricultural conditions from a list of options and subsequently determine the agricultural management options that are available for that farmer. Examples of these outputs can be seen in Appendix 5. The database was developed following extensive questionnaires and data gathering from farmers in the field, hence the information provided by the tool is focused on the end beneficiaries.

During the development of the Tanzanian DSS, communication was maintained between the team in Tanzania and the team in Nottingham via Email and limited site visits. This communication helped to ensure that the development of the DSS met the needs of the end users. Therefore limited additional training for using the tool was required following the extrapolation of the tool in the field.

Knowledge of how the Tanzanian DSS has been developed and how it should be used within the field will help any future researchers looking at the development of DSS that incorporate both quantitative and qualitative data. This research has shown the step involved for producing a DSS – including understanding of objectives, carrying out research, developing solutions, building the system and finally extrapolating the system to the end users and beneficiaries.

7.7 Comments and issues arising from this study

There were various constraints and limitations to this study, which needed to be rationalised before commencing the research.

Table 7.2 raises the issues and questions that were considered before commencing the research, as well as illustrating issues that would need to be referred to during the research.

Issues/Constraints	**Points of consideration**
Understanding the overall objective and the elements that should be included within the development of the DSS	- Resource issues – Water and nutrients - Agriculture – Type of systems applied and crops grown - Mathematical modelling – Relationship building and requirements specification - Cultural and social constraints – Governmental and local infrastructure issues - End users – The beneficiaries of the system
The strategy to be used to develop the DSS	- Data – Collection methods and the types of available data - Strategies – Various approaches could be adopted, application and development of a single coherent approach - Purpose – The actual purpose of the system will influence the approaches used
The concerns and ignorance surrounding computer modelling and computer based systems	- End users – Making the DSS suitable for the end users, production of a simple a clear cut solution to the problem of RWH management - Awareness – Ensuring all parties involved in the development of the DSS are aware of the processes being employed - Perceptions – Listening to comments from end users and recording perceptions towards any proposed solutions

Table 7.2: Issues and constraints that were considered during the development of the Tanzanian Decision Support System.

Expanding upon these points, the objective of the project clearly states an interest in water and nutrients as these resources are fundamental for the sustainability of livelihoods. They influence agricultural systems (crop growth and livestock production) and domestic life. Improved management of these resources could help to improve the livelihoods of the farmers in Tanzania for whom the DSS was developed.

Water, particularly that which falls as rain, is of utmost importance to agricultural practices in Tanzania. Collection, storage and partitioning and hence management of this resource are very important. There are adequate volumes of water in Tanzania for both domestic and agricultural use (The Independent Newspaper, 2002). However, the management and distribution of this resource is inequitable. Current allocation methods and management of water in Tanzania rely upon governmental intervention and are influenced by social status. The Tanzanian DSS illustrates an approach to management systems that incorporates all social classes to help ensure water is utilised efficiently and fairly within the community.

In principle, the application of nutrients to crops in Tanzania is only possible for richer farmers. However, the amount and form of applied nutrients depends on the source of any additional nutrient resource. There are two sources of additional nutrients. The first, being more commonplace, is the application of organic manures produced by livestock present in the farming areas and applied to the field (Cooke, 1967; Fageria, 1997). The second is inorganic fertilisers that may be added to the soil before or during crop growth. These are generally less available and more expensive than organic fertiliser options. For this reason, in the Tanzanian DSS, manure was the key nutrient source focused upon. Nitrogen was the key nutrient focused on within this study. The proportion of nitrogen in the fertility treatment is estimated by an application rate factor derived from Kourik (1986). The value for the organic fertiliser (manure) is 0.0215 and for inorganic fertiliser it is 0.3 (Norman, 1995). Hence the level of nitrogen in the applied nutrient is calculated as:

Nitrogen Applied = (0.0215*volume of manure) + (0.3*volume of inorganic fertiliser) (Kg N ha^{-1})

The reliability of this calculation needs to be questioned as it has been derived from factors determined by experiments carried out in 1986 (Kourik, 1986). The work of Loomis *et al* (1998) and Monteith *et al* (1994) into resource capture by plants helps to verify the use of this equation. It must also be noted that the application of this equation for the DSS is to act as a representative approach for determining the nutrient application. To enhance the use and reliability of this equation within the Tanzanian DSS, actual physical data captured within the field in Tanzania should be used to develop this relationship. Data collected should include nutrient application and the levels of nitrogen present in both organic and inorganic nutrient resources. With regard to the Tanzanian DSS, the focus should be on the organic nutrient resource, that of manure, as this is most commonly used by the farmers in the field (Kajiru, Personal Communication, 2003).

Both of these resources (water and nutrients) can be investigated individually. Relationships can be derived for their influence on crop growth individually or in combination as demonstrated in Chapter 5. However, these relationships are rarely integrated within a predictive model. Both resources influence crop productivity and depending on levels of the resource, at any time, one will prove more prominent in influencing crop yields. Further experimental trials on rice and maize in the field will help improve understanding of which resource has the greatest affect on yield production, based on the other field conditions such as soil type, relief of land and any additional management regime. For the Tanzanian DSS the 'law of the minimum' has been applied for determining which factor – water or nutrients – has the greatest effect on crop production. The factor that shows at an individual level the greatest effect on production is the factor that is used further within the Tanzanian DSS. Future developments to this approach should look at deriving relationships that take into account both resources within one relationship, such that crop production is seen as a product of the effects of nutrient and water application.

Agricultural systems and social/cultural issues were determined through observation and the use of questionnaires and focus groups with the communities involved in the study. The disclosed information was documented in a database, which allowed the production of look up tables. These were used for quick reference purposes to identify potential management strategies or factors that might influence the application of an approach. The relationship built between the Nottingham team and the extension officers in Tanzania helped in identifying suitable solutions for the production of the DSS. This link was further enhanced by the relationships that were built between the extension officers and the beneficiaries of the system.

Modelling and system development strategies are discussed within Chapter 3. There is an extensive range of approaches that could have been applied for the production of the DSS. It was necessary to summarise the important aspects of each approach and combine these for the production of a single and more coherent method. One important consideration when developing a strategy for DSS development (or any computer based system) is to know when to draw the line in its production and requirements specification. If an end point is not specified then the development of the system could end up being continuous, resulting in no system being developed. This has often been the case with the production of agricultural models in the past (Moulin, 1994).

The direction and approach for the development of the DSS have been covered in Chapters 3 and 5. The main points that were highlighted were in relation to the integration of numerical and social data for the production of a DSS. An important aspect is to make sure that there is a detailed set of data requirements alongside the steps to be adhered to during the production of the system. Having a strategy from the start for the production of the DSS helped to add focus and direction to the system being developed. Anon (1988) and Marakas (1998 and 2003) helped to highlight the general structure for the development of a DSS, while Sprague (1996) focuses upon the numerical considerations and Strosjinder (2001) illustrates the social aspects that could be incorporated. The above researcher's strategies have been manipulated to form the basis of the strategy outlined in this project.

The Tanzanian DSS has taken into consideration the social status and perceptions of the farmers for whom the system has been developed. By having an understanding of the different community members in the study region this helps in the uptake of any proposed management tool. Social constraints influence the partitioning of the water and nutrient resources for which this management tool was developed. By initiating a scoring method for how social constraints influence decision-making related to resource partitioning, it was possible to integrate these issues into the Tanzanian DSS. A score between 1 and 5 was given to each of the social factors that had been outlined. The higher the score given the more influential and important the factor is, with reference to the views of the individual or group being questioned. These scores were then fed into the Tanzanian DSS and used to develop a ranking score to help understand the likely success of CPR management. The most influential social factors were those of food security and wealth status. The application of a scoring system like this is a common approach to understanding wealth classifications (Ostrom, 1990). In the context of the Tanzanian DSS and the factors that were scored it would have been useful to give the option to give a score of 0 (zero) as in some instances the factor is not associated to the farmer in question – such as the access to machinery or additional labour. By increasing the scoring values to a range between 1 and 10 would help improve the reliability of the results, as it gives the farmers a greater range of choices and enables them to provide a better perception of themselves in relation to wealth classification. However, at the same time this increase in options could cause problems with giving the farmers too much choice. To resolve this, examples at each scoring level should be expressed to the farmers. Also during the process of determining wealth ranking, discussions should be held with the extension officers and village elders to help in the understanding of the scoring process and the wealth ranking criteria. This aspect within the development of the DSS is one that requires further research and discussion and offers future potential for this study.

The type of data being collected for the development of the Tanzanian DSS was of utmost importance. As illustrated in Table 7.2, various data sources were required for building the DSS. The types of data fall under two categories, quantitative (numerical) and qualitative (human perceptions) data, both of which were utilised for the production of the Tanzanian DSS. Management options were determined that considered the numerical information as well as the social status of the farmers for whom the options were being extrapolated. The numerical data collected by the team in Tanzania and supplemented by outputs from the PT model were used to develop the mathematical relationships that made up the 'model base' of the Tanzanian DSS. This data was important as it demonstrated the relationships between the resources and crop production that subsequently had to be used within the DSS. One of the objectives of the DSS was to be able to output potential yields for rice and maize based on the inputs from water and nutrients. Therefore numerical data and calculations were clearly required to fulfil this output process from the model. The use of social data and human perceptions toward management approaches (qualitative data) added an extra level to the Tanzanian DSS. From the term DSS (decision support system) already this implies a certain level of human interaction with the tool – the word "decision" evoking this, as it is humans that have the ability to make the decision as to whether to adopt an output from the DSS or not. By utilising both quantitative and qualitative data within the Tanzanian DSS additional reliability is added to the outputs from the tool as the inputs have been derived directly from the end users, and they have also been involved fully in the development of the tool. In conclusion, within the Tanzanian DSS both data types have their inherent uses but can also help to stimulate further conversations between the extension officers and the farmers by raising questions surrounding the outputs from the system. It should also be noted in relation to the data that was collected and the combining of quantitative and qualitative data that there can be cross-over between the physical and social data. Not all physical data is seen as being numerical, much of it is qualitative such as descriptions of soil types, however chemical constituents of soil will be seen as numerical. Conversely social data that has been collected can be analysed quantitatively. Such that numerical information is derived from the survey and questionnaire data that has been collected. Computer software such as N6 or Nvivo that fall under the title CAQDAS can be applied to help in the analysis of this sort of social data and help to give meaning to the numerical results and outputs.

The agricultural practices that are in place in Tanzania and how these could subsequently be improved via the application of a DSS were of great importance. The focal point was that of RWH management. Within the collection of data, additional agricultural practices were recorded. These have been documented in the database systems expressed in Chapter 5 and 6. The database system can be applied to look for common agricultural practices within a catchment. The surrounding environmental factors that are present where the practice is being undertaken are also recorded in the database. This allows for extrapolation of common techniques further afield by looking for these common factors related to soil, water and nutrient conditions for example, and assuming that the agricultural practices could be adopted. This simple observational approach helps to quickly highlight agricultural options and can be subsequently followed up with evidence for the technique that can be quantified through the DSS.

An understanding and focusing on these points has helped ensure that the production of the Tanzania DSS was focused and completed. Communication with the end users maintained the direction of the DSS. This (communication) is a key area in the development of any computerised system for solving management issues.

Limitations faced during this research centred on the data acquisition from the team in Tanzania for the relationship building and hence the development of the DSS model.

These data were not very forthcoming and the team in Nottingham had to use literature based relationships and existing models such as the PT model to derive data sets. It must be noted however, all relationships and derived data sets were verified with the scientific research team in Tanzania.

Positionality is an area of study that was touched on within Chapter Two, and should be re-iterated here. It must be restated that I was unable to travel to Tanzania to work with the team out there and collect any data sets, or experience firsthand the culture in Tanzania. Therefore I was solely reliant on the data and information being provided by the team in Tanzania for the development of the DSS. This could be seen as a limitation as these data were not very forthcoming. However it can also be seen as an advantage as it means that the information I was being given was collected solely by Tanzanians. There was no second hand manipulation of the information, or any outside factors influencing the data provided. My own personal views and interpretations of Tanzanian culture and farming systems could not cloud my judgement of the data being provided. The data and information being provided had come directly from the team in Tanzania. As a researcher, it is important to be aware of the flow of data collection and the steps it goes through before it reaches you.

7.8 Research outcomes

It can be concluded that a DSS for tackling RWH management in Tanzania has been produced that incorporates numerical data related to the influence of resource (water and nutrients) effects on crop (maize and rice) yields. It also includes social factors that affect the decision-making process for allocation of these stipulated resources – a social hierarchy ranking.

Alongside the development of the DSS, a single strategy for DSS development has been proposed that brings together the extensive amount of literature that reviews DSS development strategies. It is possible to combine these various reported methods into one approach. This has been developed and rationalised during the production of the Tanzanian DSS.

Finally an awareness of how important both quantitative and qualitative information is for aiding decision making processes has been demonstrated by the production of the Tanzanian DSS and various sub-systems (spreadsheets and databases).

7.9 Future aspect to be included within the development of DSSs

As stated in Chapter 1, this study has demonstrated the 'building blocks' of something much larger, an area of systems analysis and DSS development that until recently scientists had only scratched the surface of. It has been observed that scientists now possess the tools, methods and ability to manipulate and exploit both the theoretical and social aspects of science, and apply this, for example, to the improved production of management DSSs. At present these DSSs only tackle one management issue, such as RWH or disease and pest control. In the future it is likely that these systems will develop to be able to incorporate more than one field of study. Yet fundamentally the processes expressed within this research will contribute to the development of these DSSs – the development of a systems development strategy that incorporates both quantitative and qualitative data types to aid in the decision-making process.

As scientists it is important to be able to 'think outside the box' when developing decision support strategies. An awareness of the external factors that influence the way decisions are made should be recognised such as environmental and cultural influences. Also an understanding of the decision making process and the way that people 'think' and make choices will help in the development of future DSSs.

Decision theory (Bather, 2000) is one area that should be considered when developing DSSs. All the time we are awake and sometimes when we are asleep, something is going through our heads. To this uncontrolled coursing of ideas through our heads the name of 'thinking' is given. It is automatic and unregulated. No one can tell another person how they should think or what decisions they should make. It is possible however to describe the different ways in which people think and therefore determine a better strategy for thinking and decision making (Dewey, 1933; Gladwell, 2006).

Thinking begins in what may be called a *forked road* situation, a situation that is ambiguous, that presents a dilemma, and that proposes alternatives (Dewey, 1933).

This *forked road* analogy illustrates how the application of a DSS can be made as DSSs aim to illustrate options and alternatives for solving an outlined situation.

Alongside the factors that influence the way humans think and make decisions, body language and culture could also be considered as factors that have an impact on a chosen decision and the potential outcome of the decision process (Wagner, 1981; Pease 1997). For example, whether or not an individual feels comfortable with a chosen management approach can be determined by observing their body language – facial expressions and speech patterns. These sorts of observations could be recorded during the data collection period (PHASE 1) (focus groups) of the strategy outlined by this research, as it will help to add confidence to the information that has been provided by the individuals being questioned.

It is difficult to fake body language. Therefore recording and observing the physical actions of an individual during a discussion is a good way to help understand and interpret whether they are being truthful in what they say. With regard to decision-making this is a useful tool as the interpreter will be able to determine the views of the individual or group towards a series of alternative options. This can be determined through discussions and the recording of the reactions displayed by the participants.

The application of this theory behind the way humans think and make decisions, alongside the interpretation of body language can be applied to the development of DSSs as the theories will help to add extra weighting and reliability to the outcomes of the developed systems. The focus of DSS development should be on the potential users of the systems; hence a sound understanding of the subject matter (end users and area of study) is required. This has been displayed by the production of the strategy for the development of the Tanzanian DSS as it was identified that both numerical and social data would be needed for the development of the DSS to tackle the issue of RWH in Tanzania.

Further studies and applications of the theories behind CPR could be applied. Within the developed DSS, the function of the land could be investigated. The DSS could present two scenarios – land owned or land cultivated. Alongside this investigation into land use, an investigation into the number of potential participants in CPR method could be applied. This would generate two transparent ‘fair’ scenarios that could be taken up for further consideration by the communities as to whether CPR is worthwhile. It would also show how different socio-economic groups could benefit from CPR. The assumption must be made that the water is allocated fairly in the first place or poor farmers would never want to be involved in the strategies and CPR could not exist.

The Tanzanian DSS at present introduces fourteen social factors of which users of the system are able to give a weighting score of 1 to 5. Future developments of the system could see the number of these social factors being applied becoming more focused. From this research it has been observed that the two factors that have the most influence on community decision-making are food security and perception of social status. Also livestock ownership should be considered in greater depth as it is seen as one of the most important factors when determining wealth status in Tanzania. It would be advisable that the development of any new DSS application that incorporates CPR factors should focus more on the perceptions displayed by the community in relation to wealth status and food security.

A final development point for the enhancement of this DSS would be to give greater focus to the application of GIS techniques. An objective of scientific research is to solve problems that are of real world concern, for example the improvement of resource management in Tanzania as expressed in this thesis. The application of GIS methods is one way to improve and rationalise the effective and efficient allocation of resources, in accordance with clearly stated criteria – whether it be physical construction of infrastructure in utilities applications, or scattering fertiliser in precision agriculture (Longley *et al*, 2001). GIS methods look at four levels of abstraction (Figure 7.1) and cover the two fundamental aspects of DSS development – an understanding of human orientated issues (human perceptions towards management, the social factor investigated within this study) alongside an understanding of computer/model orientated systems and issues (the numerical relationships and the application of programming approaches for the development of the DSS).

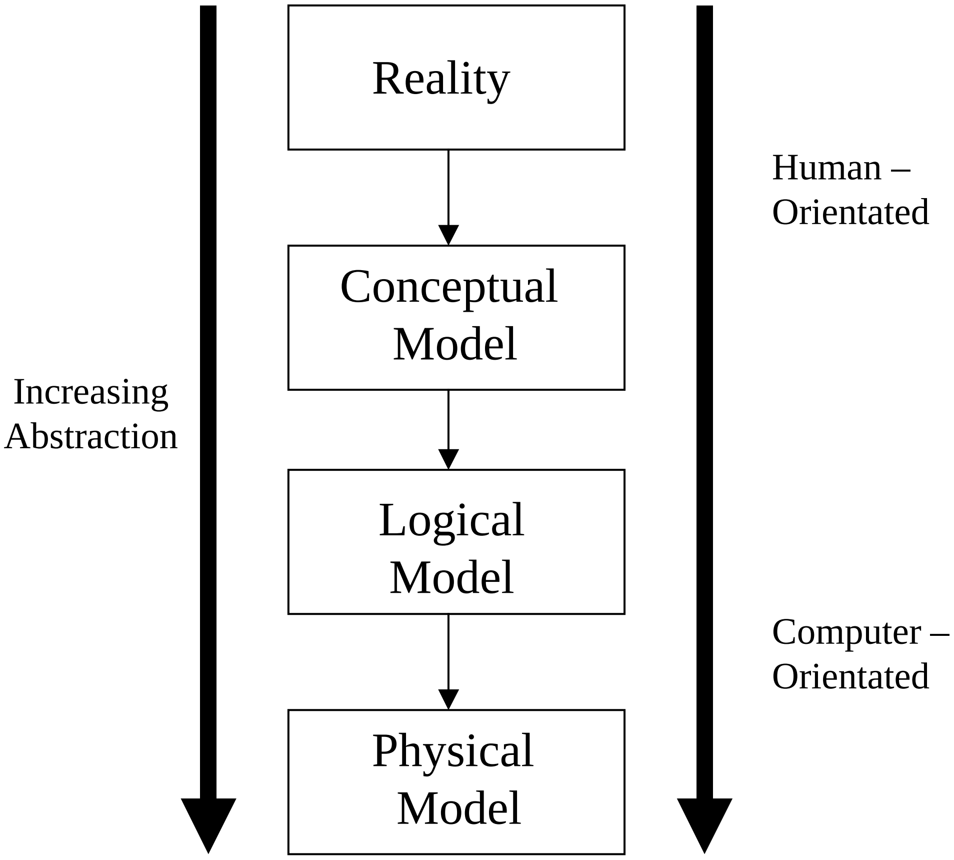


Figure 7.1: Levels of abstraction relevant to GIS data models (Longley, 2001)

The three development aspects expressed above could all help contribute to improving the developed DSS as expressed in this thesis. The future of this research lies in a greater understanding and application of decision theory, CPR issues and GIS techniques.

It is important to be aware when developing any new management strategy that the derived solution may not be accepted by the end user. In an article in The Independent newspaper, Dowden (March 5th, 2004) states: "Want to help Africa? Then get off their backs".

PODIUM

Want to help Africa? Then get off their backs

Richard Dowden

From a speech at the Royal Geographical Society by the Director of the Royal African Society

BECAUSE AFRICA looks poor and has weak institutions, we imagine that Africa is weak. We think it needs saving. We like to believe that if we bring our money, our knowledge, our skills to Africa, we can lift it out of its misery. Our strength, wisdom and kindness will lead Africans out of darkness and into a better world – a world like ours.

This is the missionary approach to Africa and it's quite prevalent these days. Its roots lie in the Christian missionaries who marched into Africa in the 19th century. Much of the colonial service had a similar idea when Britain and other European countries tried to rule Africa. Its successors today are the aid agencies, the modern missionaries.

The problem with this approach to Africa is that it has not worked. Billions of pounds worth of aid has poured into Africa in the past 50 years. I suggest as a starting point that the development of peoples, of societies, can only be done by those people themselves. It cannot be done by outsiders. Outsiders can support, but they cannot impose unless they want to take over the governance of the whole continent. We've tried that – it was called the British Empire and it didn't work.

So stop feeding money to European cows and spreading it on fields of cotton and corn that can be grown far more cheaply in Africa. Get rid of the agricultural subsidies that make a mockery of our proclaimed faith in the free market. Stop keeping African goods out of our markets. Allow Africans to earn a living in the world. We should, in short, get off their backs.

Figure 7.2: Newpaper article – "Want to help Africa?" (2004) (http://comment.independent.co.uk/commentators/article72223.ece)

To help ensure better RWH agriculture, developing techniques such as the Tanzanian DSS is often not enough. There is a need to develop effective regional management plans, rather than rely on *ad hoc* efforts (Barrow, 1999). Such management should:

- determine priorities;
- prepare contingency plans to deal with problems;
- constantly assess progress;
- be adaptive;
- share information.

These areas should be considered when undergoing any future development of agricultural management decision support systems.

7.10 Final Words

In the year 2000, Kerr stated that rainfed agricultural growth was nearly stagnant in the semi-arid tropics, and that the Green Revolution technologies had had little impact. In the year 2006, a greater amount of research had been instigated into understanding and managing the water resource that is available (Pearce, 2006). With our ever-changing climate, scientific research into improved water management systems has increased greatly as our demand for water has turned us into vampires, draining the world of its lifeblood (Pearce, 2006).

2005 was the 'Year of Water' and various initiatives were instigated to help raise awareness towards the need to manage water resources, instigated by 'Water Aid'. A supplement from The Times newspaper 'Focus Report – Water' (March 2005) illustrated just how important it is that we begin to manage our use of water. Outlined below are 9 of the headlines that were discussed in this report, each of which highlights the importance of water as a resource for the maintenance of human livelihoods.

"Water – more likely than oil to cause this century's wars"
"About three to four million people die each year from waterborne disease"
"It takes 1,000 tons of water to produce one ton of grain"
"The joy of not having to spend six hours to collect one can of water – how a cheap pipeline makes a difference"

"The relentless fight for the right to clean water"
"Education suffers in the struggle for clean water"
"Tap revolutionises village life"
"Rainwater harvesting must be promoted"
"It's time to match aid promises with action"

From the above headlines, the 8th one mentions the importance of RWH, which was the focus of this study. Therefore it can be concluded that this research was extremely topical and important for helping to understand approaches to the management of water resources. For examples of these headline stories refer to the appendix.

The work of Water Aid did not end in 2005. Articles in New Scientist (February, 2006) detail how important it is that we have an understanding and awareness of the way we use and manage our water reserves. It takes staggering quantities of water to grow some crops (see Table 7.3) – water that many countries cannot afford to lose.

Consumable	Volume of water needed
1 kilo coffee	20,000 litres
1 quarter-pounder hamburger	11,000 litres
1 cotton t-shirt	7000 litres
1 kilo cheese	5000 litres
1 kilo rice	5000 litres
1 kilo sugar	3000 litres
1 litre milk	2000 litres
1 kilo wheat	1000 litres

Table 7.3: Volume of water needed to grow some "crops" (adapted from Pearce, 2006)

It is not only the developing countries like those in Africa that need to be aware of water management and shortages. Water management is a worldwide issue. This has been demonstrated by an article from The Independent Newspaper (July, 2006) titled "Where has all the water gone?" The article states how

- Britain is drying up
- The Tiber is reduced to puddles
- Chinese villagers are queuing for a drink
- Californian forests are ablaze

All of the above are influenced by the fact that water resources are depleting and water reserves are not being replenished.

Drought is seen as a bad thing and in the past it was always thought of being a regional occurrence, which would be balanced out by moisture and greenery somewhere else in the country. However in 2006 drought and water shortages are starting to look like a global phenomenon - 'The world seems to be drying up' (McCarthy, 2006).

Across the Earth, right now, there are empty rivers, cracked reservoir beds, failing crops, forest fires, and water shortages for people and livestock. It is likely that this is principally a result of global warming and a change in our environment.

Conversely, the year 2007 has seen some of the worst flooding events in the UK and flash flooding events in East and Central and West Africa, which are being attributed to climate change. Also the US has suffered from its worst drought since the Great Depression (Independent Newspaper, June 2007). For details of these events refer to the Appendix related to Newspaper articles.

Therefore research such as that demonstrated within this thesis (the development of a strategy and DSS for RWH management) should be seen as fundamental in maintaining our natural environment and for sustaining human livelihoods as we move into the year 2008 and beyond.

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"Computers are useless, they only give you answers"

(Pablo Picasso)

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- Extent of RWH in WPLL and Maswa
- Database of institutions for managing CPR in Maswa
- Needs for training, awareness and information
- Local indicators of soil fertility in Maswa
- Local criteria for identifying groups of the poor in WPLL and Maswa
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APPENDIX

Photographic representation of study regions

Newspaper articles

Meeting notes and photographs

Villagisation costs and benefits

Tanzanian DSS

Spreadsheets and Database

Example programming code

Reports and data sets

"Science may never come up with a better communication system than the coffee break"

APPENDIX 1

Additional photographs of the study regions taken by Dr Sayed Azam-Ali during a research visit (2003)

Maize crop – Photograph taken in the Maswa District

Water channel which could be tapped and used for irrigation purposes.

Geophrey Kajiru from the SUA team carrying out some soil profiling experimentation – obtaining a soil core.

The establishment of the maize crop in Maswa. Researchers and farmers overseeing the trial plots.

Farmers working with a rice crop. The photograph illustrates the capture of water that can be used for helping the growth of the crop – WPLL district.

Maize crop in Maswa

Farmers and agricultural researchers working in the WPLL. Establishment of the rice crop and capturing of water resources.

The maize crop in Maswa reaching the stage of harvesting.

APPENDIX 2

Newspaper Articles

WHERE HAS ALL THE WATER GONE?


HOWDEN
RESERVOIR

Water — more likely than oil to cause this century's wars

People power grows in battle to control water

It takes 20,000 litres of water to grow 1 kilo of coffee,

11,000 litres of water to

make a quarter pounder, and 5000 litres of water to make 1 kilo of cheese

No wonder the Earth is running dry...

Rainwater harvesting must be promoted

The landless state of many in Bangladesh adds to their woes, says **Renata Rubnikowicz**

WATERAID

Bangladesh suffers from its very low-lying status. In rural areas just 10 per cent of the population has access to proper lavatory facilities

IT IS hard to believe that a country such as Bangladesh could have a water problem. If anything, it would seem to have too much of the wet stuff.

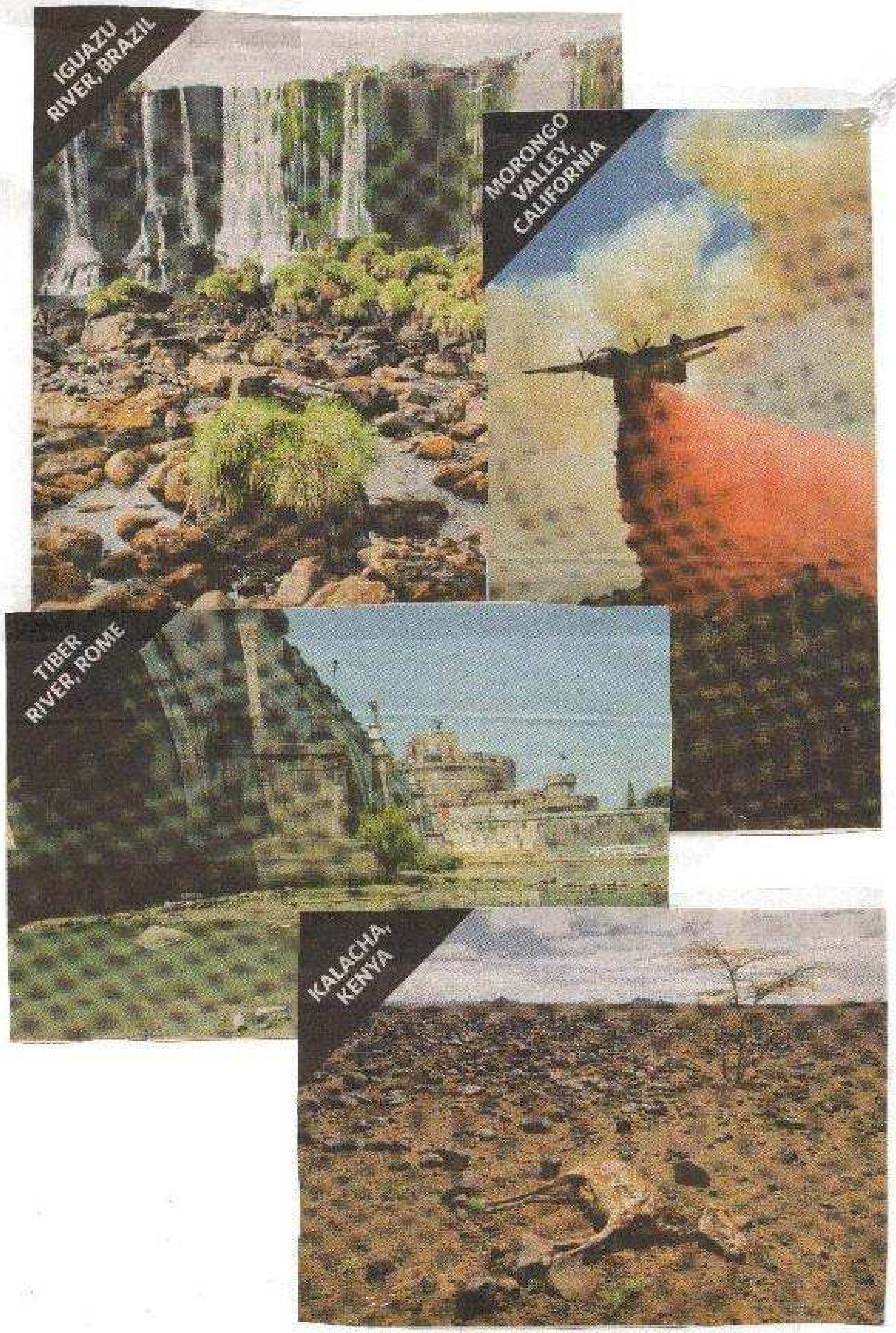
Hundreds of rivers flow from the Himalayas, including the Ganges, before they meet in the Bay of Bengal, and it is deluged by monsoon rains from June to October. In Bangladesh almost 150 million people are trying to support themselves on less than 144,000sq km (55,600sq miles) of mostly low lying land. About half the population lives below the poverty line. In rural areas, they try to make a living growing rice, but there is too little land to support everyone. Many move to cities, such as Chittagong or the capital Dhaka, to work in garment factories.

"The tubewell is the main source of drinking water," says Khandker Zakir Hossain, WaterAid's representative. "But in certain areas people still drink pond water or water from streams. They don't boil water because they have no money for fuel. Although there is such a long monsoon, people do not collect rainwater. WaterAid is trying to promote rainwater harvesting but resources are scarce and the attitude to do it still needs to be developed."

The problems of the poor are compounded by their landless state: many have no right to live anywhere, whether in city slum or on flood-prone delta islands. For WaterAid and its local partners, bringing clean water and sanitation is far from simple. The solution does not just lie in boring a well or digging a latrine. Often, agreements to sink a tubewell or build a sanitation block must be sought from city corporations, big companies and landowners on whose property the poor are squatting.

Now everyone from government leaders to the poorest peasant is involved in a national sanitation campaign. The goal is to bring universal sanitation to the country by 2010.

WaterAid was a catalyst in starting the campaign. It began in 2003 with every October being declared national sanitation month. In the first month, a study found that only a third of Bangladeshis had access to sanitary lavatories and in rural areas this fell to about 10 per cent.


IGUAZU RIVER, BRAZIL
MORONGO VALLEY, CALIFORNIA
TIBER RIVER, ROME
KALACHA, KENYA

Severe flooding hits one million Africans

By Steve Bloomfield
Africa Correspondent

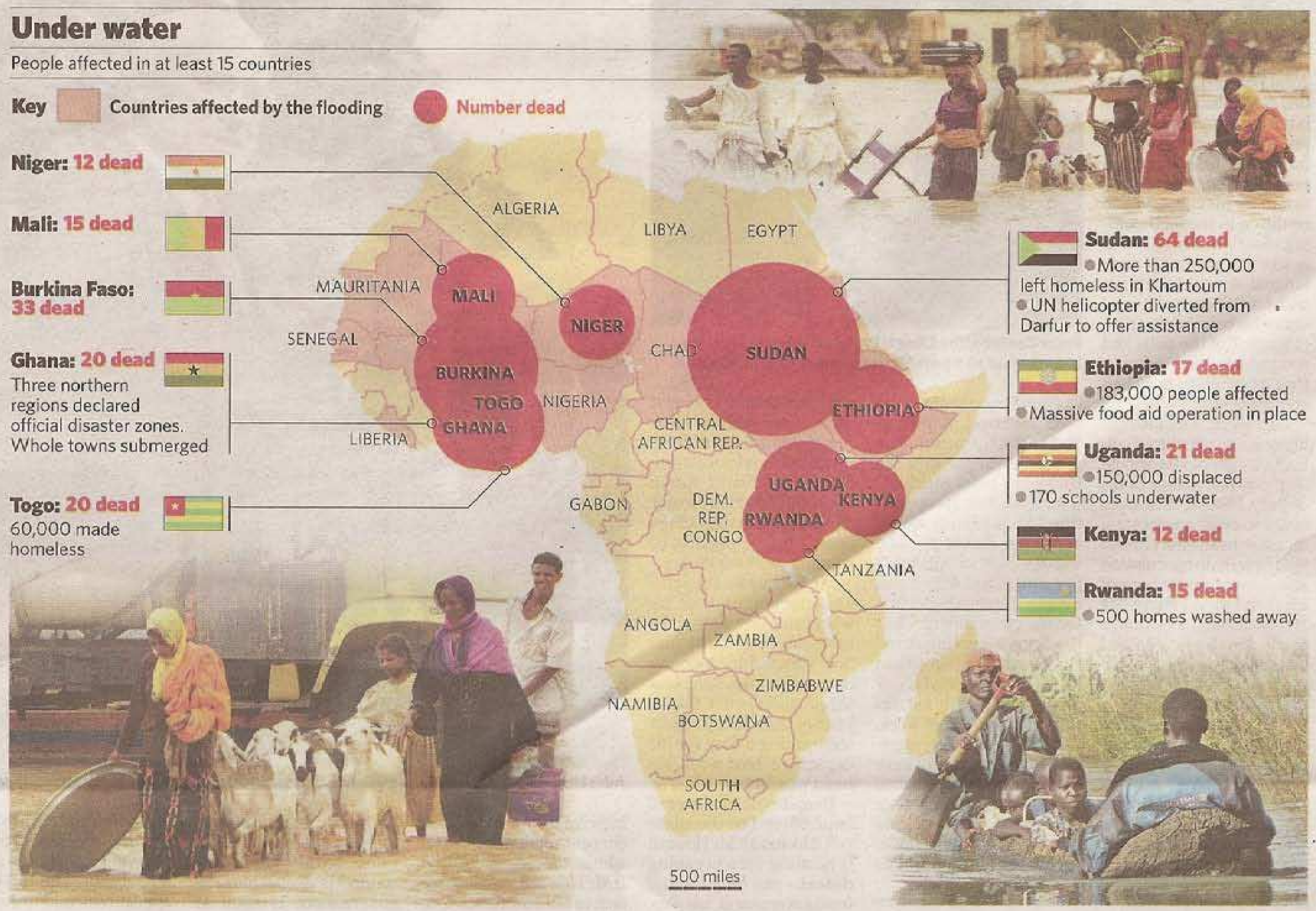
Severe flooding across east, central and west Africa has destroyed hundreds of thousands of homes, killing at least 250 people, and washing away much of the continent's most fertile farmland. More rain is expected and aid agencies are warning that the need for food, shelter and medicine in the affected regions is urgent.

By last night at least 15 countries across Africa were thought to be affected by the flooding, from Senegal in the west to Kenya in the east. West Africa has suffered most with deaths recorded in Burkina Faso, Togo, Mali and Niger.

Ghana has been hardest hit, with an estimated 400,000 affected, many of whom are now homeless. At least 20 people have died and the floods have also washed away much of the region's crops and livestock. The country's Information Minister, Oboshie-Sai Cofie, said: "It is a humanitarian disaster. People have nowhere to go."

There are fears that the worst is yet to come as those affected by flooding fall prey to waterborne diseases such as cholera. United Nations spokeswoman for humanitarian affairs, Stephanie Bunker, said: "The situation is bad and more rain is likely."

The UN's situation report into the flooding last week said more than half a million people in 12 countries have been affected. The new situation report, due out later this week, is expected to put the number affected at more than one million in at least



put in place. Even so more than 250,000 have been left homeless in the Sudanese capital, Khar-

people have been displaced and 21 people have died. In many parts of northern Uganda people have

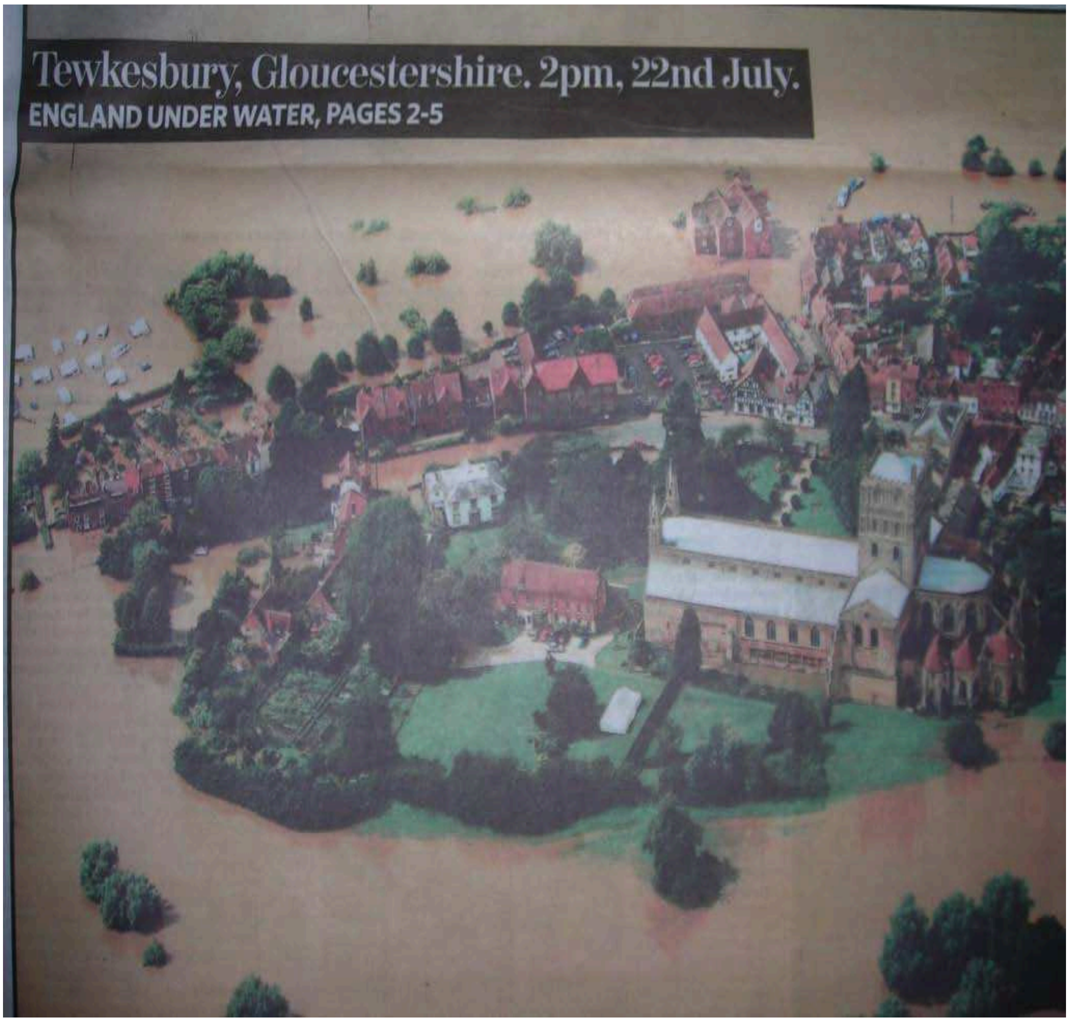
of people only planted for the first time this year," she said. "Now most of their fields are

collapsed and hundreds of homes have been destroyed.

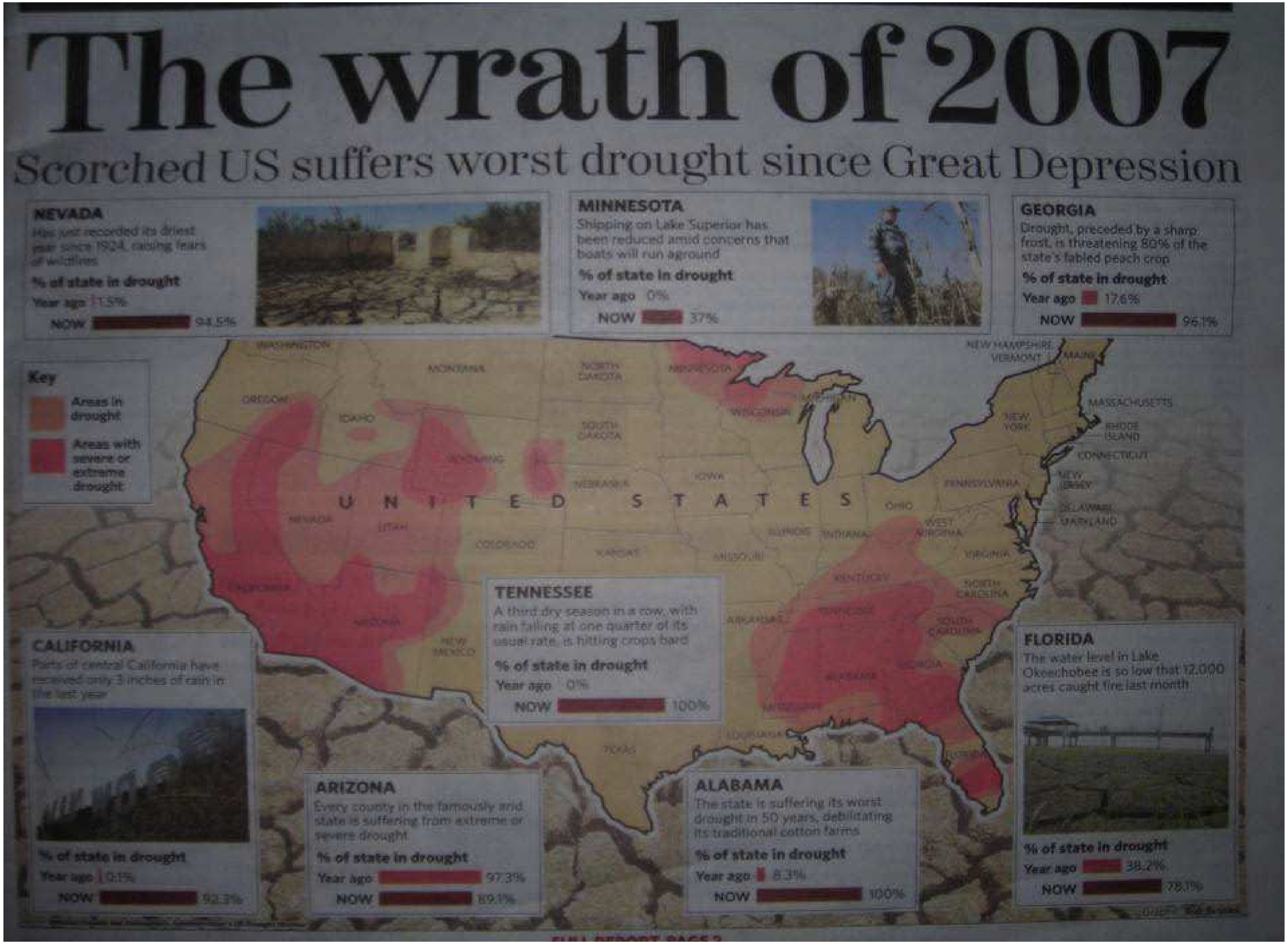
Some parts of Africa have

particularly bad. Beatrice Spadacini, a spokeswoman for Care, said the organisation was on "high


INEXTRA
THE GREAT FLOOD
Torrential rain sweeps Britain in day of drama and devastation
Tynemouth
Up to three inches of rain and near gale-force winds caused rough seas.
Hessle
A 28-year-old man died after his foot was trapped in a metal grating.
Leeds
More than 70 houses in the Halton area of Leeds had to be abandoned.
Wellington
A tornado swept across the countryside, reflecting the 'huge amount of energy' in the thunder clouds, according to the Met Office.
Cheltenham
Fire service has many reports of flood water breaching cellars; locals report roads like rivers.
Lydney
Up to 50 children were rescued after a bus became stranded in flood water in the Forest of Dean town.
Bideford
Heavy rain caused streams to overflow their banks, flooding dozens of properties.
Glastonbury
Thousands of fans delayed leaving the music festival; police handed out 3,000 space blankets.
Hull
Received at least four inches of rain; hundreds of homes flooded.
Sheffield
Police searching for 13-year-old boy find body in river Sheaf; traffic gridlocked as drivers abandon vehicles; at least 100 people rescued in Brightside area.
Wimbledon
Ten matches cancelled and many others, including Tim Henman's, are halted by rain.
Flood
Full report, page 2


Tewkesbury, Gloucestershire. 2pm, 22nd July.
ENGLAND UNDER WATER, PAGES 2-5


Flood
WHAT LIES
BENEATH
As the filthy flood waters begin to subside,
they are revealing a scene of devastated
homes. Now there are warnings of
a mounting health risk from
toxic chemicals and fatal
bugs left behind in
the wake of the
deluge
FULL REPORTS
PAGES 2&3



The wrath of 2007

Scorched US suffers worst drought since Great Depression

NEVADA
Has just recorded its driest year since 1924, raising fears of wildfires
% of state in drought
Year ago 11.5%
NOW 94.5%

MINNESOTA
Shipping on Lake Superior has been reduced amid concerns that boats will run aground
% of state in drought
Year ago 0%
NOW 37%

GEORGIA
Drought, preceded by a sharp frost, is threatening 80% of the state's fabled peach crop
% of state in drought
Year ago 17.6%
NOW 96.1%

Key
Areas in drought
Areas with severe or extreme drought

TENNESSEE
A third dry season in a row, with rain falling at one quarter of its usual rate, is hitting crops hard
% of state in drought
Year ago 0%
NOW 100%

CALIFORNIA
Parts of central California have received only 3 inches of rain in the last year
% of state in drought
Year ago 0.1%
NOW 92.3%

ARIZONA
Every county in the famously arid state is suffering from extreme or severe drought
% of state in drought
Year ago 97.3%
NOW 89.1%

ALABAMA
The state is suffering its worst drought in 50 years, debilitating its traditional cotton farms
% of state in drought
Year ago 8.3%
NOW 100%

FLORIDA
The water level in Lake Okeechobee is so low that 12,000 acres caught fire last month
% of state in drought
Year ago 38.2%
NOW 78.1%


MEDIA PLANET
WATER MANAGEMENT
3 JULY 2007
SUSTAINABLE WAYS TO COPE WITH FLOODS, DROUGHTS AND SHORTAGES

APPENDIX 3

Meeting notes

Geophrey Kajiru and Abeid Msangi working in the Tropical Crops Research Unit (TCRU) at Nottingham University. Below shows Omari Mzirai in the TCRU.

Discussion and ideas building during a meeting held between the SUA team and the team in Nottingham. Participants in the meeting included Geophrey Kajiru, Abeid Msangi, Omari Mzirai and Henry Mahoo from the SUA team, and Robin Burgess, Dr Sayed Azam-Ali and Dr Sarah Jewitt from the team in Nottingham.

Outlined below are the notes and some of the actions that were generated during a project meeting held between Robin Burgess and Omari Mzirai. The focus of the meeting was on the use of the PT model for the development of the DSS.

Summary of the meeting:

15th April 2003

The following highlights points of discussion that were tackled during the visit to Nottingham (to meet with Robin Burgess) from Omari Mzirai. It gives rise to action points and the work currently being performed by both Robin and Omari. The main focus of discussion was related to project R8115 and the future development of the nutrient/fertility aspect of the Parched-Thirst model (project R8088).

- A report has been written and circulated by Robin in relation to the Nutrients – Nutrient pointers and improvement of the Fertility aspect of the Parched-Thirst model.
- Feedback has been received and this has given rise to the realization that reports have been written and are in the process of being written that cover points highlighted within the Nutrient Document. (See attached document). This will help to allow for an improvement in this first draft of the document, and should also lead to the development of the sound database that will be accessed within the newly programmed Nutrient/Fertility component.
- This Nutrient document was the basis of the discussions held on the 15th April 2003.
- It is evident that experiments are being carried out that are investigating the effects of altered levels of fertilizer application on the yields of crops. This was brought to our attention by Geoffrey Kajiru. The experimental design was outlined briefly giving details of the different environmental conditions that were trying to be maintained.
- It was suggested by Omari that it may be a good idea for the people at Nottingham to carry out a few trial plots of crops in the glasshouses whereby the conditions that are present in Tanzania can be simulated – in relation to temperature, water levels, fertilizer application, crop cultivar grown in Tanzania etc – and see the effects on the crop yields.
- The reason for this would be to increase the datasets for this area, also this information could then be used for validation purposes once the new fertility component has been developed.
- Various considerations will have to be adhered to before experiments of this type can be performed such as legality of using the same cultivars as in Tanzania, as well as whether this is a feasible way forward/action/experiment that can be carried out at Nottingham – this all needs investigating.
- It was brought to my attention that earlier projects have been carried out in the field of fertilizer application and yields etc. These reports need to be obtained and data extrapolated from them, also if database exist data should be obtained.

- This previous data in conjunction with those which are currently collected in R8115 project can be used as the basis for building the new fertility component – used for testing and the formulation of mathematical relationships.
- Data is needed for the building of conversion factors (use of existing data and databases) and data is needed for validation purposes (controlled experiments and other new experimental work/data).
- From the initial document related to Nutrients it was discussed how the number of variables could be reduced and which of the mentioned variables were important for use within the model/decision aide. Many of them could be combined such as application methods and how much is added. The concept of regulations could almost be discounted from the equation as there are few regulations that are currently known. The cost of fertilizers was highlighted as an important point as farmers are limited by their capital as to how much fertilizer they can buy and therefore how much they can apply to their crops – ultimately this will influence the yield they can obtain for their crops. However, these farmers still want to know that the potential of their crops is based upon whatever levels of fertilizer they are able to apply. This is an important area that needs to be made clear within the model – that whatever levels are added/used, the best case scenario is highlighted for that particular farmer.
- It is of utmost importance that views as to what extension officers, scientists and the farmers see as being important characteristics that influence fertility and crop yields are known, as these can then be programmed into the new fertility parameter. Information needs to be circulated between all.
- We need knowledge and an understanding of what the views are from 'stakeholders' in Tanzania. And how they analyse their soil fertility. This will help to narrow down the scope of inputs that will be programmed within the new fertility part of Parched-Thirst and should help to make it more user-friendly and site/'people' specific – i.e. the information is related to areas that have been highlighted by those people who will be using the models.
- The model needs to help with planning and give rise to suitable decisions and scenarios that can help farmers. For example: Questions should be asked

within the model such as “Do your crops/plants look yellow?” Whether or not the farmer answers yes of no, the next step should lead onto a possible solution and highlight the problem to the farmer. Such as saying…”If yes, then try adding so much of X fertilizer…”. This can also then lead into further questions that can help to lead to an even more precise management decision that can be employed by the farmers.

- Other factors that influence yield also need to be considered in relation to their effects on fertility of soils etc. For example, environmental conditions, particularly related to water. It will be important to formulate a relationship between the runon and runoff of water in relation to the levels of nutrients still in the water, i.e. what are the effects of leeching? Data and information will be needed to produce this equilibrium equation.
- Good and bad soil fertility indicators need to be analysed and highlighted in relation to what stakeholders perceive as the most important areas. This information can also be included within the fertility component of Parched-Thirst.
- These specific factors/equations need to be determined, cross-referenced and validated – has any of this work been done yet?
- NUD*IST or N6 will be used to help analyse any reports that are formulated following discussions with the different groups of farmers/people in Tanzania. This tool will be able to highlight gender, age, class… issues. Reflecting the different perceptions and opinions portrayed by people. (See attached document highlighting the importance of qualitative data analysis etc).
- With regards to the actual programming that needs to be carried out the area of interest with the Parched-Thirst model is to do with the altering of profiles. Visual Basic is the programming language that will be used to perform these alterations as it is the language that Parched-Thirst is currently written in. (See attached document highlighting the justification behind the use of Visual Basic as the programming language).
- It will be necessary to look at the existing code and see where the fertility parameter fits into the whole picture/scenario.
- It was suggested that the new fertility component should be written as a function or a series of functions, in a block format. This will help the

understanding of what has been done and will help the incorporation of it into the existing model. It must be noted that the acquisition of data is fundamental to the formulation of these functions.

- By drawing up specific flowcharts and diagrams it will be possible to easily see the direction in which these functions are and should be going. This will help to introduce the various ‘if’, ‘then’, ‘while’, and ‘else’ scenarios that can be programmed within the model using Visual Basic’s coding methods.
- It is necessary to get hold of reports when they are made available to ensure the continuation of this development. With regard to this point, Omari has suggested the setting up of a Web page on SWMRG website where all reports which are out can be uploaded and downloaded in PDF format so they can be accessed by all partners and interested parties interested in the work. This should eliminate problems with getting hole of reports etc.

The next points highlight what is to be done – the next steps in the progression of the fertility component of the Parched-Thirst model.

- Find out whether and when it might be possible to set up some plots of crops to act as controls in the glasshouses in Nottingham. (RWB)
- See whether there may be any legality issues involved in this. (RWB)
- Possibility of an MSc student carrying out this work? (RWB)
- Are there any existing data and reports that are available related to nutrient consideration and fertilizers etc… (ALL)
- Send reports that have been written to the relevant people. (ALL)
- When will reports R1 and R7 be available? – preferably a data is needed.
- Information gathering and analysis of perceptions from stakeholders is of utmost importance for the continuation of development and the development of the required equations etc. (Tanzanian group need to keep us posted on this)
- Equations and relationships need to be developed and researched. (RWB and OM)
- Setting up of a Website to help the accessing of reports etc. (SWMRG/OM)
- Enquire at Nottingham whether this can also be done. (RWB)

- Investigate the existing code for the Parched-Thirst model and highlight where and when the fertility component is used/invoked, and what it is used for. (OM)
- Set up relevant flowcharts for relationships. (RWB)

RWB – Robin Burgess to investigate
OM – Omari Mzirai to investigate
All – Everyone to work on.

This was a very productive meeting whereby ideas and progress was discussed. Areas of interest have become apparent and work can begin to focus more upon the actual development and design of the new fertility component within the Parched-Thirst model.

Liasons will continue between Robin and Omari to ensure the continuation of the development and work on project R8115.

Also during this meeting Omari met with Martin Itomuh and discussed his PhD and work – which was of great benefit to Martin.

Plus information related to N6 formerly known as NUD*IST will be distributed shortly to help all in the understanding of how the program will be used and incorporated as an analysis tool. This will be provided by RWB.

RWB will also hold discussions with his supervisors to gain their views on what has been discussed today etc…

The above meeting report compiled by Omari Mzirai helps to illustrate one of the meetings held between the SUA team and the team from Nottingham. What was discussed is highlighted as well as future actions.

APPENDIX 4

Villagisation costs and benefits

Table 1 highlights some of the costs and benefits associated with villagisation.

Aspect	Comments adapted from Lorgen (1999)
Costs	The economic costs can be divided into those associated with living in villages and the short-term costs of the move itself (Coulson 1982). In Tanzania, the marketed production of almost all crops fell. The total costs of the villagisation, including the value of property destroyed, the direct costs of the 'operations', and the value of crops that were not planted or harvested, were very great indeed (Coulson 1982). Schemes such as villagisation tend to have extremely high costs of administration. For households, increased distance from agricultural land is often considered the primary economic cost (Pankhurst, 1992). Joint and individual labour time is also costly in villagisation. Coulson makes the point that the costs are not only financial; "the social cost is an uncooperative peasantry" (Coulson, 1977)
Service Provison	Villagisation is often imposed on rural populations with the justification that it is 'for their own good'. This argument is clearly present in the claim by governments that villagisation will facilitate the delivery of services, such as health care, education, or marketing, to previously scattered populations. Despite the paternalistic nature of a 'for their own good' argument, it must be said that service provision is the area where villagisation attracts the most praise. Where schools and clinics were built and functioning, villagers appreciated the services and felt that their quality of life had improved. However, some problems exist with the service provision argument. The first is that the promised services often did not appear. A study of villagisation in Tanzania notes a lesson: 'Don't advertise what you can't deliver' (Lappé and Beccar-Varela 1980). In Tanzania, it has been argued that the government created impossible demands for services, thus embarrassing itself and upsetting village dwellers. "Angered when expected services did not materialise, villagers understandably doubly resented efforts to make them produce more. In some cases, the reaction of villagers has been to sabotage production" (Lappé and Beccar-Varela 1980).
Agricultural production	Along with increased access to services, villagisation is often justified on the basis of increased agricultural production. In Tanzania, problems with the state's input delivery system, associated with villagisation, affected agricultural production (Bryceson 1990). Untimely delivery and poor storage of inputs reduced their efficacy, and some inputs were wrong or even harmful for the different agroeconomic zones in the country. Use of inputs required additional labour, and villagisation had exacerbated labour shortages (Bryceson 1990). But not only villagisation affects agricultural production, the issues are not clear-cut.
Land: Use and Rights	Issues around land are closely linked to the above discussion of agricultural production. People were very concerned about land ownership and the loss of rights to land which often accompanied villagisation. Many people in Tanzania were settled on land belonging to other villagers and were uncertain of future claims to the land. New conflicts developed over claims to uncultivated lands that were under cultivation prior to villagisation (Swantz 1996).
The Environment	Villagisation had environmental consequences as a result of the concentration of dwellings, people, and livestock.). In Tanzania, villagisation made soil fertility an immediate problem (Coulson 1982). Planners neglected both the soil and the water aspects. Villagisation has effects on the living environment for animals and people as well. Tanzania witnessed unprecedented cholera and typhoid epidemics (Coulson 1982), also the return of the tsetse fly which kills animals.

Community harmony and disharmony	Villagisation often managed to add to community harmony and disharmony simultaneously. In 1978, Anacleti examined the issue of community harmony with villagisation in Tanzania and its impact on culture. He found that young people liked the semblance of a town. Older people thought it broke social solidarity. Now it is more accepted.
Control/ Protection	Control and protection of rural populations are arguably two sides of the same coin; both reduce individual freedom, and efforts at control may be called protection, somewhat euphemistically, in situations of insecurity. In terms of security, it can be considered safer to live together in a village than alone in a homestead.
Compulsion/ Participation	The issue of control is directly linked to the issue of how much force or compulsion was used in villagisation and, on the other hand, how much rural populations were able to participate in the planning of the process. It has been argued extensively that decisions about villagisation should be subject to participatory decision-making. In Tanzania, "the way in which villages were created hardly encouraged grass-roots participation, because there were such obvious shows of government force, and so little time for discussion or real planning" (Coulson 1982).
Villages as models of local Governments	Strong local government may be a way to take advantage of a village infrastructure and to maximise the positive aspects of villagisation. Of particular relevance here is Wily's (1998) study of forest commons as communal property in Tanzania. She argues that a "statutorily-defined institutional framework for common property management is already well-established at the community level and able to be brought into play" in Tanzania (1998). She argues that the village councils created in the 1975 Villages Act and upheld in a further Act in 1982 are well placed for community-based forest management.

Table 1: Examples of costs and benefits associated with villagisation.

APPENDIX 5

Programming code and Tanzanian DSS

The files and documents within the attached CD (**Tanzanian DSS**) contain the following:

File/Folder Name	Contents
Database	This folder contains the database that was developed in Microsoft Access that allows the extension officers to perform simple lookups based upon the existing agricultural conditions, and determine possible management methods.
Information	This folder contains information to help the user of the Tanzanian DSS understand its capabilities. It contains the 'Help' file, along with a report that was compiled to stipulate the conclusion of the production of the DSS.
Photos	These are screen shots that have been used within the help file and the production of the tool
Photos_work	These files link with the overall system
Spreadsheets	This folder contains the various spreadsheets that were developed during the development of the DSS. They can be used for housing scoring of the various attributes that are discussed within the qualitative aspect of this study. They are automated to help give rise to a better understanding of preferred management options following focus groups and discussions with farmers in the study regions.
Tanzania Model	This is the executable model
Tanzania Code etc	This folder contains the Delphi code that was used for the production of the tool.
Tanzania	This is back up information related to the tool
Model Information	This is further back up of information for the tool.

Tanzanian DSS – User manual and CD

APPENDIX 6

Example data sets and project reports.

The following CD (**Documentation**) contains various reports that were compiled during this research that help to give a greater understanding of the study. Various data sets are also expressed that were used for the building of the various relationships used for model development. The table below lists what is on the CD.

Folder	Contents	Comments
Meetings	Questions for Dr Sayed Azam-Ali	This document lists a series of questions that we compiled to be asked at a team meeting held out in Tanzania. It covers various issues of the research.
	Summary of meeting	Here are some notes that were produced following a meeting held at the University of Nottingham between the Nottingham researchers and the team from Tanzania.
Data	Costs provided by Tanzania	A list of costs to be inputted within the model
	Crop investigation	Investigating the growth of crops based on different agricultural inputs.
	Data used for model development	30 years of data generated from the PT model, used for model development
	PT output	An example output from the PT model
	PT output	Further outputs
	Further rainfall data	Rainfall data generated by the PT model and provided by the team in Tanzania
	Grain Yields	Data provided by the team in Tanzania
	Harvest details	Data provided by the team in Tanzania
	Investigating the affect of slope on yield production	An example of changing the slope input in PT and the corresponding outputs
	Nutrient investigation	Investigating changes in nutrient application
	Phase one modelling	This initial model that was developed in Excel
	Rainfall data	Data provided by the team in Tanzania and through the use of PT.
	Water example	An example of changing the water inputs within PT
Reports	Baseline information	Provided by the team in Tanzania
	Bukangilija soil data	Provided by the team in Tanzania for helping to understand existing conditions
	Delphi vs Visual Basic	Report compiled by the team in Nottingham when deciding which programming language to use for model development.
	Quarterly report	An example of a quarterly report
	Extent of RWH in WPLL	Report compiled by the team in Tanzania

	Extent of RWH in Maswa	Report compiled by the team in Tanzania
	Identifying poor classes in Tanzania	Useful for understanding the potential wealth classification criteria
	Improving CPR management	A short report related to an aspect of the research
	Local criteria groups of poor	More notes to help with understanding the communities in Tanzania
	Local indicators of soil fertility	Report on soil fertility in the study regions
	Management institutions	Institutions involved in the research
	Maswa database	A database set up for the region of Maswa
	Maswa social data part 1	Outputs from the questionnaires etc
	Maswa social data part 2	Outputs from the questionnaires etc
	Maswa social data part 3	Outputs from the questionnaires etc
	Methodology manuals	Research methodologies used
	Monitoring and evaluation framework	Frameworks set up throughout the research
	Needs for training	Reasons why training is required in Tanzania
	Notes about the questionnaire	Notes that explain the questionnaire that was developed by the team in Tanzania and Nottingham
	Nutrient management report	A short report of nutrient application in Tanzania
	Nutrient pointers	A report compiled by the team in Nottingham associated with understanding the nutrient aspects of the research
	Procedures and methods	Procedures and methods used throughout the research
	Social sciences questionnaire	The questionnaire that was implemented in the field
	Training of extension staff	Notes on how to train the extension staff
	WPLL database	Database related to the region of WPLL

Meetings, Data and Reports CD