Report to the Water Research Commission

# INCREASING ECONOMIC EFFICIENCY OF WATER AND ENERGY USE FOR IRRIGATION AT WHOLE FARM LEVEL IN THE WINTERTON AREA

## VOLUME II

by


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The research is published in three volumes. Volume I comprises the executive summary as well as the summaries of Volumes II and III. Volume II, entitled ***Increasing economic efficiency of water and energy use for irrigation at whole farm level in the Winterton area*** is dealt with in this report. The title of Volume III reads ***Die ontwikkeling van 'n besluitnemingsondersteuningstelsel vir die ekonomiese evaluering van risiko-bestuur op plaasvlak en die toepassing daarvan in die halfdroë gebied benede die P.K. le Rouxdam.*** Each of the six chapters of Volume III, however, is concluded with an English summary.

The pilot committee that monitored the progress of the project was:

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| Mr DS van der Merwe | Water Research Commission (Chairman) |
| Dr GC Green | Water Research Commission |
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| Prof MF Viljoen | University of the Orange Free State |

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Signed:

**LK OOSTHUIZEN**
PROFESSOR and PROJECT LEADER

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# INTRODUCTION

JHF Botes, P Breytenbach and LK Oosthuizen

## 1. INTRODUCTION

In 1980 agriculture was the largest user of South Africa's already limited water supply. The Department of Water Affairs anticipated that the demand for irrigation water will have increased by an additional 39,7 % by the year 2010 (Department of Water Affairs, 1986).

In the past the increasing demand for irrigation water was met by developing new water sources or by transferring water from areas where water was not limited. At present, however, the potential for developing new water resources is very limited, because most of the water resources are already fully utilized or the development costs are too high.

An excellent example of the demand for irrigation water exceeding the availability is the Winterton irrigation area in Western Natal. In an effort to address this problem, the Water Research Commission funded a research project the aim of which was to develop and introduce more sophisticated irrigation-information strategies for farmers. Irrigation farmers, research institutions and policy makers are interested in determining the economic value and benefits of using more sophisticated irrigation information.

## 2. THE WINTERTON IRRIGATION AREA[1]

Winterton, with specific reference to the irrigation area, is the research area of this section of the report. The total area under irrigation is 5 192 ha (Department of Agriculture and Water Supply, 1986). The research done by Botes (1994) in Winterton on a simulation and optimization approach to estimate the value of irrigation-scheduling information for decision makers under risk, is presently the only work done in the agricultural economic field by the University of The Orange Free State in this specific area.

The Drakensberg forms a natural watershed and the western boundary of the area. The general slope is to the east and the farming area is split by three major river systems, the

1. The description of this research area is mainly based on information obtained from Hogg (1993).

Little Tugela River, Sterkspruit and Lindequespruit. The Sterkspruit and Lindequespruit flow into the Little Tugela River that eventually flows into the Big Tugela River. The Big Tugela River forms the northern boundary of the area. The most important water sources are indicated on a map of the area in Figure 1.

## 2.1 Location

The Winterton irrigation area is located between longitudes 29°24' to 29°42' east and latitudes 28°45' to 29°00' south. Figure 2 shows that the irrigation area to the south is situated alongside the Sterkspruit and the Little Tugela River. Figure 3 indicates that the irrigation area runs from west to east along the Lindequespruit and the Little Tugela River. The green circles on the maps indicate centre pivot irrigation in this area.

The area falls within the Estcourt magisterial district. The N3 forms the eastern boundary and the residential areas of Maqedandaba and Nkomokazini the southern boundary. The Eastern Free State forms the western boundary and Lesotho the southern boundary. The Kliprivier district forms the north-eastern and south-eastern boundaries.

## 2.2 Topography

The landscape is partly broken in comparison with the Orange Free State and is about 1 030 m above sea level. The western area is mountainous, while the rest of the area can be described as undulating.

Currently the total area under irrigation is approximately 5 192 ha while 7 010 ha is scheduled for irrigation purposes (Department of Agriculture and Water Supply, 1986). The possibility of extending the irrigation land exists, but as a result of limited availability of water, this extension is restricted. The land size varies between 10 and 200 ha.

The average pumping height from the Little Tugela River is about 41 m but varies from 3 to 160 m. The pumping height out of the Sterkspruit varies from 13 to 146 m with an average of 62 m. The Lindequespruit is lower than the above-mentioned water sources and the average pumping height is 29 m with a variation of 6 to 50 m. It is therefore clear that the Winterton area is considerably uneven with varying pumping heights.

## 2.3 Climatic conditions

Kwazulu/Natal is divided into eleven bioclimatological groups representing areas with the same climate (Department of Agriculture and Water Supply, 1986). Two bioclimatological groups, namely 6 and 8, are found in the Winterton area. Bioclimatological group 6 runs from the Drakensberg to the road that links Winterton and the residential areas of Loskop. Bioclimatological group 8 is situated from the above-mentioned road to the N3.

The Winterton area is predominantly a summer rainfall area. High rainfall occurs but in late January and early February dry spells are experienced that cause major stress in crops. For both bioclimatological groups 6 and 8 the average annual rainfall varies between 700 and 1 000 mm (Department of Agriculture and Water Supply, 1986). Bioclimatological group 8 is drier than bioclimatological group 6 and the drier area is referred to as a so-called "rain shadow" that restrains the rain. About 82,9 % of the annual rainfall occurs from October to March which is the summer rainfall season. It is therefore clear that the area is suited for summer crop production because of the high summer rainfall.

In the Winterton area frost can be expected from the 15th of May and continues until the 25th of August. If frost occurs too late it causes damage to wheat in its flowering season. Furthermore the prevailing temperatures, combined with frost, affect the growing season. The warmest temperatures occur during December, January and February whilst the coldest temperatures are experienced during July and August. Widespread hail is not generally experienced in the Winterton area and can be expected in summer as well as in winter. Hail occurs more regularly in bioclimatological group 6 than in 8. Furthermore there are definite hail belts within the area, where damage can be expected on a more regular basis.

This area is known for its mountain winds that blow from the mountains from a westerly direction. The wind blows nonstop for days during August and October. This causes the farmers to cease irrigation because of the loss of water and the negative consequences on wheat production. The mountain winds also cause problems during January and February. High temperatures and the dry mountain winds effect severe stress in crops and subsequently yield losses. The combination of the above-mentioned factors is the principal cause of drought during these two months. Furthermore, especially the maize gets blown down by the strong winds during April to June.

## 2.4 Soil types

Very few areas in South Africa dispose of such a variation of soil types as Natal. The Winterton area is no exception and to generalize would be erroneous. For the classification of soil, the area can be devided into the two bioclimatological groups.

Bioclimatological group 6 consists primarily of Hutton and Avalon soil although soil types such as Clovelly, Griffin, Estcourt, Westleigh and Longlands are also present to a lesser degree. The clay content of soil in the area varies between 35 and 55 %. Hutton is the most common soil type in bioclimatological group 8 whereas Avalon also occurs frequently. Marginal soil types like Westleigh, Estcourt and Longlands are more distinctive of bioclimatological group 8 than group 6. The clay content of the latter group varies between 25 and 35 %.

Cultivated fields in the area can include three or more of the above-mentioned soils, rendering land preparation, planting and irrigation difficult. The high clay percentage of the soils in the two areas also influence the above-mentioned practices.

## 2.5 Water resources

As mentioned earlier there are three rivers that supply the irrigation farmers of Winterton with water. The underground water is well dispersed and of good quality. Underground water is used for domestic and livestock watering purposes only. There are no boreholes that are strong enough to be used for irrigation purposes. Droughts also affect underground water and debilitate the water pressure. However, during normal and wet years there usually is enough water.

A group of irrigation farmers along the Sterkspruit has built their own dam (Bellpark) in the upper part of the river. The majority of the farmers settled along the river participated in this project. The reason for building the dam was to ensure that there would be sufficient water for irrigation during winter time. A drawback of the Lindequespruit and the Little Tugela River is that there are still many irrigation farmers who do not have dams. This fact causes enormous problems, especially in winter months.

## 2.6 Irrigation management

In general the farmers irrigate against the slopes. The irrigation systems are well designed for the various slopes.

With the assistance of personnel of the University of the Orange Free State, the farmers were made aware of the benefits of irrigation scheduling. During 1989 and 1990 the co-operative made funds available for erecting weather stations in the area. Readings were taken weekly and a scheduling approach was developed by means of a computer program. This information was strategically placed to make it readily available to the farmers. In conjunction with the previous development the Water Research Commission launched a project in this area under the guidance of Mottram and De Jager (1994). The primary objective of this project was to maximize the efficiency of water use on an irrigation project.

Wheat, soybeans and maize are the major crops that are produced under irrigation. Cash crops like cabbage and potatoes are also produced but to a lesser degree. A considerable number of crop diseases spread to this area during the last five years and diseases which were considered to be of minor importance become problematic. The occurrence of these diseases is due to the fact that double harvests are produced under irrigation.

### 2.7 Natural vegetation

In bioclimatological group 6 the veld is generally acid. The veld has a carrying capacity of 1 LSU per 4 hectares. The quality of the grass is relatively poor and therefore the maintenance cost of livestock during the winter months can be very expensive. The veld in bioclimatological group 8 is relatively sweater and of a better quality than that of bioclimatological group 6, with a carrying capacity of approximately 3 hectares per LSU.

Redgrass is the most common grass type found in the Winterton area. Numerous farmers established cultivated pastures on the old fields that were withdrawn from production. Kikuyu and ryegrass are the most common cultivated pastures.

Plantations are limited in this area. Earlier black wattles were frequently planted here. However, the trees became a problem and many farmers weed it out completely. Plantation companies bought farms in the bioclimatological group 6 and planted Saligna and Pine trees. However, the area thus used is relatively small.

### 2.8 Economic location

#### 2.8.1 Road transport network

Winterton is linked with a tarred road to Bergville in the west, Ladysmith in the north east, Estcourt to the south east and the N3 to the east. As mentioned the N3 forms the eastern boundary of the area and is the main route between the Orange Free State/Eastern Transvaal and Kwazulu/Natal. The roads in the area are predominantly tarred and in a fair condition. Good gravel roads link irrigation farms to the tarred roads. The farms are situated approximately 15 km from Winterton. The nearest silo and co-operative are found in Winterton. The nearest livestock market is in Bergville, 20 km from Winterton.

### 2.8.2 Railway network

Winterton and Bergville are situated on a siding and presently the two areas are served three times a week. Farmers in the area mostly use the station in Estcourt which is situated 40 km from Winterton. However, the farmers seldom use railway transport.

### 2.8.3 Road transportation

Railway transport is supplemented by road transport but the latter is used more often. There are numerous private transport services in Winterton that are managed by *individuals and farmers. The majority of farmers use their own means of transportation to* bring the harvest to the grain silos and livestock to the markets. Contractors are only used during peak times.

### 2.8.4 Service centres

The Natal Agricultural Co-operative is situated in Winterton and is the service centre for the area. The farmers do most of their business here. AGRICO does the majority of irrigation designs and is situated in Estcourt. Large capital purchases are done in Ladysmith, Estcourt and even Pietermaritzburg. Winterton supplies in the basic daily consumer needs.

Grain is delivered to the co-operative in Winterton from where it is transported to the respective mills. Hog production has increased over the last few years and the nearest market is the hog abattoir in Estcourt. Beef production is well established in the area. Local auction sales as well as butchers serve as outlets. Furthermore beef is also transported to the Bergville and Cato Ridge abattoirs. Vegetables, which are grown on small scale are sold locally. It is also sold to travelling hawkers trading in the vicinity.

## 2.9 Human resources

Ten percent of the farmers are thirty years and younger and 38 % are fifty years and older. Thus the majority of farmers, 52 %, is between the ages of thirty and fifty years.

This information were obtained from a questionnaire that was completed by farmers in the area. Twenty-six percent of the farmers has ten years or less farming experience, while the largest number of farmers, 32 %, has between ten and twenty years of farming experience. The number decreases after 20 years of experience so that 22 % falls in the twenty to thirty category, 16 % between thirty to forty while 4 % has more than 40 years of farming experience.

As far as type of business arrangement is concerned, 76 % of the farmers are single proprietors, 20 % farm in a partnership or closed corporation and 4 % of the farms form a company or trust.

Agriculture is the main source of employment for the black population of Winterton. As in the rest of South Africa the unemployment rate is high and is conducive to theft, especially of livestock. The residential area of Loskop supplies farmers with sufficient labourers, especially casual labourers. A considerable number of farmers have built houses for their permanent labourers whilst others say that the labourers prefer to stay in the traditional kraals.

### 2.10 Future irrigation development

Most of the land in the area is already developed and land situated near water is irrigated. The most restrictive factor in the area is the availability of water. The potential of the present rivers and dams is currently exploited fully. The building of dams in the Little Tugela River and the Lindequespruit is possible forthcoming projects. The possibility of pumping water from the Spioenkop Dam to the various catchmentdams from where it will be distributed to farmers, is under consideration. However, certain limitations will have to be investigated before implementing these projects.

The water pumped from the Spioenkop Dam will provide only in the needs of a small section of the irrigation community. If the cost of the project exceeds the advantages, the project will most probably prove to be financially unfeasible.

## 3. PROBLEM STATEMENT

Irrigation farmers in the Winterton area, research institutions and policy makers are unsure about the economic value and benefits of better irrigation information to individual decision makers with different risk preferences when production conditions are variable and the availability of irrigation water is limited. The lack of reliable estimates of the value of irrigation information may be one reason why irrigation farmers are hesitant to adopt more sophisticated strategies.

The value of better irrigation information to specific farmers is uncertain, because farmers have different objectives in mind when they select an irrigation-information strategy. Other factors that may affect the amount irrigation farmers would be willing to pay for better soil-water, plant-growth and weather information, are soil quality, the availability of irrigation water and the correlation between returns yielded by other income sources and returns yielded by the irrigation enterprise.

Irrigation water is scheduled in an uncertain environment. The irrigation farmer cannot determine the amount of water in the soil and future plant water demands with certainty. Consequently, irrigation farmers are not sure how much water they need to apply and when they should apply it. An irrigation farmer will use information if he feels it will help him realize his personal objectives.

Better irrigation information will provide farmers with more knowledge of soil-water levels and future plant water demands. However, the irrigation farmer must still process the information according to specific decision rules (which are influenced by farmers' objectives) in order to decide when to irrigate and how much water to apply.

A problem which arises when estimating the value of better irrigation information, is that of determining how the information can be used to best advantage. In other words, the optimal decision rule for scheduling irrigation water must be selected for a decision maker with specific risk preferences, given the specific irrigation information used and the personal objectives of the decision maker. To determine the most appropriate decision rule for scheduling irrigation water, a simulation optimization approach must be developed. Crop-growth simulation models must first be validated to determine their suitability for analyzing the economics of crop production. The biological crop-growth simulation model must then be linked to an economic subroutine, an irrigation scheduling subroutine and an efficient search optimizer. Another problem when estimating the value of better irrigation information, is that of measuring and incorporating the personal objectives of decision makers correctly.

## 4. RESEARCH OBJECTIVES

The main objective of this research was to determine what irrigation farmers in the Winterton area can and will be willing to pay in order to obtain more sophisticated soil-water, plant-growth and weather information. Six alternative irrigation-information scheduling strategies, which differ in terms of the type and quality of soil-water, plant-growth and weather information were evaluated. The evaluations were done on a representative irrigation farm in the Winterton area with two soil types.

The objectives of the research were the following:

Firstly a procedure for the formulation of representative farms for the research area had to be suggested and used. These farms would serve as basis for economic analyses.

Secondly, to determine how the value of irrigation information is affected by type and quality of information, the availability of irrigation water, the soil's plant extractable soil water (PESW), the decision maker's absolute risk-aversion coefficient (RAC), and the relationship between weather and product prices. Outcome distributions before and after obtaining information were compared, because the value of better irrigation information is derived from the ability of information to provide a more desirable distribution of net returns. Different levels of information were compared after the optimal decision rule for initiating irrigation with each information level had been obtained.

Thirdly, to show how information levels and risk attitudes affect the optimal decision rule for initiating irrigation under conditions of unlimited and limited water supply on two soil types with different PESW.

Fourthly, to develop a simulation optimization model for the optimization of irrigation decisions under dynamic plant-growth conditions. This approach combines components of biological crop growth sub-models, and an economic sub-model with irrigation scheduling and optimization routines capable of yielding realistic estimates of the value of irrigation information under variable production conditions.

Fifthly, to obtain absolute risk-aversion coefficients (RAC) for irrigation farmers in the Winterton area that reflect risk preferences towards annual income risk. Other objectives concerning the elicitation of risk preferences were, firstly, to determine whether risk preferences towards annual income differ from preferences towards wealth risk; secondly, to determine whether decision makers show constant absolute risk aversion as levels of annual income and wealth increase; and, finally, to determine whether the consistency in respect of the measurement of annual income and wealth risk preferences, changes when the levels of annual income and wealth increase.

*Sixthly, to identify and adapt a general procedure for validating crop-growth simulation* models to account for the importance of cumulative distributions of yields and net returns. Other objectives in respect of model validation were, firstly, to assess the validity of the IBSNAT and PUTU irrigation models in terms of their ability to analyze the economics of crop production under diverse production conditions in South Africa; and, secondly, to determine whether the errors resulting from the crop-growth simulation model are more important to risk-seeking, risk-neutral or risk-averse decision makers.

*Seventhly, the effects of pumping restrictions on irrigation efficiency had to be* determined. The time-of-use electricity option of ESKOM must be analyzed and its effect on the management of scheduling will be determined by means of the developed model.

## 5. COMPOSITION OF THE REPORT

This section of the report consists of an introduction, six chapters and conclusions. The six chapters follow one another in a logical manner with a view to addressing relevant questions concerning the value of irrigation information comprehensively. A typical irrigation farm in the Winterton area was constructed to render the assessment of irrigation information under conditions of unlimited and limited water supply on soils with different PESW possible. All the chapters consist, firstly, of an introduction delimiting the field of research, followed by a problem statement and objectives. Then the conceptual model addressing the theoretical aspects of the stated research problem is presented. The section on the conceptual model ends with conclusions drawn from the literature review. The empirical model including discussion of the procedures used follows next. All the results are presented and discussed in the next section. All the chapters end with conclusions drawn from the results and an exposition of implications for further research.

Chapter 1 deals with the identification of nine representative farms for the Winterton irrigation area. The advantages of the development of representative farms are found in the fact that different types of farmers can identify themselves with the farm situations. The fact that a large number of farmers could be involved in this way, served as motivation to use RFs rather than identifying single farms or average farms in the area.

The main objective of Chapter 2 was assessment of two crop-growth simulation models commonly in use in South Africa in terms of their ability to analyze the economics of crop production under diverse production conditions in South Africa correctly. Critical characteristics affecting the assessment of model performance were identified and used to adjust general validation techniques, specifically to account for the fact that the economics of crop production focus on the cumulative distribution function of net returns which are affected by yields and water use.

In Chapter 3 six alternative irrigation-information strategies, using different types and quality of soil-water, plant-growth and weather information are presented, along with a representative irrigation farm. The CERES maize model (selected in Chapter 2), an economic model, an irrigation model and an efficient search optimizer to develop a simulation optimization model (called SIMCOM) are applied to this information. The SIMCOM model is used to optimize alternative management decisions under dynamic plant-growth conditions in order to estimate the value of better irrigation information.

The main objective of Chapter 4 was to elicit risk preferences of irrigation farmers in the Winterton area to make possible the assessment of irrigation information for non-neutral decision makers. Other objectives were to determine whether risk attitudes towards annual income risk are substantially different from risk attitudes towards wealth risk, and to determine whether decision makers will have constant absolute risk-aversion functions over increasing levels of annual income and wealth.

The main objective of Chapter 5 was to determine the amount irrigation farmers in the Winterton area with non-neutral risk preferences would be willing to pay for more sophisticated soil-water, plant-growth and weather information. Other objectives of this chapter were to determine the extent to which the value of irrigation information is affected by type and quality of information, the availability of irrigation water, the soil's PESW, the RAC used and perfectly negatively correlated yields and product prices.

In Chapter 6 the time-of-use option developed by ESKOM is investigated. The effects of this option on the expected net profit, yield, amount of water supplied as well as irrigation management were established by means of the SIMCOM model. Furthermore the incentives needed by the irrigation farmers to prevent them from losing out when applying pumping restrictions were determined. Finally the influence of certain variables on the number of incentives was determined.

In the last section of this part of the report, the conclusions of the research are presented along with the main implications and possible areas for further research.

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# CHAPTER 1

## THE FORMULATION OF REPRESENTATIVE FARMS IN THE WINTERTON IRRIGATION AREA

P Breytenbach and LK Oosthuizen

### 1.1 INTRODUCTION

The importance of on-farm as well as regional agricultural-economic research has increased considerably during recent years. The use of representative farms enables researchers to evaluate the influence of changes in policy and macro variables, as well as the importance of economic and technical variables, at whole farm level. Consequently, a representative farm can be seen as an instrument which ensures flexibility where research data are required at farm level (Oosthuizen and Meiring, 1992:43). If representative farms are specified correctly, the use of this approach can economize research resources and research can be applicable to a larger range of farms (Hatch, Gustafson, Baum and Harrington, 1982:31).

Van Wyk (1991) points out that the crisis in which primary agriculture finds itself, is *inter alia* the result of a lack of timely information concerning economic and financial circumstances. In order to counteract this deficiency, the Directorate of Agricultural Economics is at present identifying representative farm models in certain areas to evaluate the effect of policy decisions and aid schemes. The concept of representative farms was also applied in the following research projects: the determination of the effect of economic and physical variables at farm level (Du Toit and Van Zyl, 1989), the analysis of irrigation development for the Great Fish River Valley (Backeberg, 1984), the evaluation of the influence of resource programmes on farms (Swart, 1989) and the economic analysis of alternative risk-management strategies at farm level (Oosthuizen and Meiring, 1992).

Representative farms have already been developed for the Bergville magisterial district (Van Wyk, 1991). The method used in formulating these representative farms is very vague, however, and does not reflect the diversity of the area. A need clearly exists for representative farms in the Winterton area to be composed in such a way that the diversity in the farm businesses can be taken into consideration in economic and financial analyses.

*The objective of this chapter is to formulate representative farms (RFs) for the* Winterton irrigation area which can be used to determine the value of irrigation information for decision makers under risk. The objective with the RFs is a determining factor in the composition of such a unit. RFs are formulated according to a fixed- and variable-resource situation. The liability structure, which is not necessarily typical of the RFs, but which appears in the region, constitutes a further component of the RFs.

## 1.2 THEORETICAL BACKGROUND

### 1.2.1 Development

Elliott (1928) was one of the first researchers to use the typical farm concept in agricultural-economic research. He defines a typical farm as one which is representative of a group of farm businesses executing in the same activities. Since the typical farm defined here, is not necessarily an average of the represented farm businesses, preference is given to a modal concept.

During the sixties Plaxico and Tweeten (1963) propagated the idea that a typical farm should rather be a weighted average of the representative farms. This caused a movement away from the modal concept and they point out that RFs should be based on representative resource situations.

During the sixties and seventies many researchers used the average representative farm for the deduction of supply functions. However, they were more interested in the reaction on a regional rather than an on-farm basis. These researchers are Sheehy and McAlexander (1965), Sharples (1969) and Zepp and McAlexander (1969). The movement away from the modal concept continued.

Hatch *et al.* (1982) completed the research started by Strickland and Fawcett (1978). In this research the "Census Typical Farm Program" was developed, which contains information on farm business structures at local and regional level (Hatch, *et al.*, 1982:1). These researchers moved back towards the modal concept.

In a study on the typical farm theory in agricultural research, Feuz and Skold (1991) determined a methodology for the classification of typical farms as well as a method for the selection of a farm which is representative of others. Here too, a modal concept is used and reasons are stated for not making use of an average farm.

### 1.2.2 Definition

Swart (1989:77) as well as Van Wyk (1991:1) defines a RF as the most common type of farm situation found in a homogeneous geographic area, or which will be applicable to a certain group of farmers in an area. Hatch *et al.* (1982:1) and Du Toit and Van Zyl (1989:2) both indicate that a typical farm should be specified in such a manner that it comprises the largest number of actual farms.

A typical farm according to a modal concept differs completely from a typical farm according to an average concept (Feuz and Skold, 1991:49). The difference is to a large extent dependant on the method used to develop the typical farm. These researchers also agree that a typical farm should be representative of a number of farms.

According to Odendaal, Schoonees, Swanepoel, Du Toit and Booysen (1991) the term "representative" means "the image or expression of being something" whereas "typical" means "characteristic". A representative or typical farm can be seen as one which reflects the nature of a number of farms in the area (Oosthuizen and Meiring, 1992:45). It is therefore clear that a representative or typical farm is an abstract of the reality since it contains some of the components which exist in reality.

### 1.2.3 The use of representative farms

Hatch *et al.* (1982:31) give three reasons why the economic analysis of typical farms is useful. Policy makers require a means for measuring prosperity and the influence of policies at farm level. The influence of variables which affect the economical sphere within which farms operate, as well as the direct influence of variables on farms can be determined. Economic success of farm businesses can also be measured.

Many researchers use typical farms to analyze the effect of macro variables (Elliott, 1928; Du Toit and Van Zyl, 1989). Typical farms are also used in determining the influence of changes in policy and budgetary decisions (Plaxico and Tweeten, 1963; Swart, 1989) Sharples (1969), and Sheehy and McAlexander (1965) use typical farms when analyzing the response to supply functions.

At farm level RFs are used in the evaluation of alternative risk-management strategies (Oosthuizen and Meiring, 1992) as well as to analyze dairy farm enterprises and classify them into groups with equal production potential, for application in linear programming

(Fox and Driver, 1980). It is therefore obvious that RFs promote and facilitate research at farm level. The results of this research can then be applied to actual farms, provided that the typical farms are properly formulated and the research is applied with the necessary restraint.

### 1.2.4 The formulation of representative farms

Oosthuizen and Meiring (1992:46) quote Hatch *et al.* (1982) who indicate that the specification of a typical farm is not easy and is normally associated with concepts of average and mode. When using an average typical farm, Feuz and Skold (1991:52) indicate that production could be over-estimated and that more production possibilities could be created which might lead to production misconception. The most important feature of a typical farm is that the resource base and the technological constraints should be typical and not average (Feuz and Skold, 1991:53). As early as the twenties Elliot (1928) moved away from the average concept and proved why the modal concept was preferable. Likewise, Backeberg (1984:106) warned against the use of average values as criteria where the specific variable shows a skewed distribution, a situation which is common in agriculture.

From the literature it is therefore apparent that preference should be given to the modal concept rather than the average concept. By using the modal interval in frequency distributions, a value which is more representative can be obtained (Oosthuizen and Meiring, 1992:46). Swart (1989:83) points out that analyses might be misleading because interval sizes and cutpoints could influence frequencies. This problem can be surmounted to a great extent if the purpose of each variable is determined.

The objective with the RFs determines the variables to be used. Collinson (1983), as quoted by Feuz and Skold (1991:48), identifies three common criteria for the classification of typical farms, namely (1) the pattern of climate and soil; (2) general farming practices; and (3) the ratio of labour to land. In all studies surface is identified as one of the variables (Hatch *et al.*, 1982:32; Backeberg, 1984:92; Du Toit and Van Zyl, 1989:84; Swart, 1989:84; Feuz and Skold, 1991:54; Oosthuizen and Meiring, 1992:52). Other variables used in identifying RFs are *inter alia*, farming practices, labour, available technology, capital items, economic situation of farm businesses, crop enterprises and livestock enterprises. It is obvious, however, that if the above-mentioned were to be taken into consideration in formulating RFs, there would be so many RFs that all of them could not be modelled. It is therefore advisable to identify only a few criteria for the formulation of RFs.

Mail questionnaires and group discussions are the methods most often used locally to obtain data for the identification of RFs. Swart (1989), Du Toit and Van Zyl (1989) as well as Oosthuizen and Meiring (1992) used these methods, while Swart (1989:52-61) and Du Toit and Van Zyl (1989:1-2) discuss the pros and cons of the various methods. Information can also be gathered by means of personal surveys. This method is often not practical because of the vastness and inaccessibility of some areas, as well as the fact that it is very expensive. The biggest advantage pertaining to the method is that a high response rate is obtained because the questionnaire is delivered personally and the questioner is present when the respondent completes it. The nature of the data, as well as the reliability of data acquired, will often determine the best method for obtaining information (Oosthuizen and Meiring, 1992:47).

According to Feuz and Skold (1991:55) there are two important requirements typical farms should meet and which should be kept in mind. The first is whether the typical farm suits the description of those specific farms and the second whether the technology, available resources and management practices included in the typical farm are representative of the group of farms. Three important aspects referred to by Feuz and Skold (1991:53) should be kept in mind when formulating typical farms. First of all the type of farm business should be identified. Secondly, farming practices should be analyzed and classified, and in the last instance the typical farm should supply the desired level of information.

Hatch *et al.* (1982:1-2) followed a three step procedure in formulating typical farms. The first step was the identification of the types of farm businesses and the production regions. Secondly he analyzed the characteristics of the farm business, such as size, crop combinations and livestock enterprises and finally he developed enterprise budgets and adapted it to whole farm level. However, his studies were aimed at regional level which meant that he had to identify as many representative units as possible.

Oosthuizen and Meiring (1992:49) define a RF as a resource situation with which a reasonable number of farmers can associate themselves and which differs from other resource situations to such an extent that these differences can be expected to result in different economic and financial outcome. Based on this definition Oosthuizen and Meiring (1992:49-50) follow four steps before analyzing a RF economically. This four step procedure for the formulation of RFs is suitable for economic analyses at farm level.

## 1.3 PROCEDURE

The objective with the formulation of RFs for the Winterton area, is to determine the value of irrigation information for decision makers under risk. It is therefore obvious that the RFs should include the largest possible number of farms as possible so that the results obtained from the analyses can be used as directives for the farms.

Oosthuizen and Meiring's (1992:49) objective for the formulation of RFs also deal with management strategies. As in the case of Oosthuizen and Meiring (1992:49) this leads to a situation where a RF are defined as a resource situation with which a reasonable number of farmers can associate themselves and which differs from other resource situations to such an extent that these differences can be expected to result in different economic and financial results. In this case no distinction is made between the number of farms owned by every farmer.

The four-step procedure for the economic analysis of RFs as developed by Oosthuizen and Meiring (1992:49-50) is discussed briefly. The first step is to determine the alternative fixed-resource situation found in the area. The importance of each situation is determined according to the number of farmers finding themselves in similar circumstances. In these analyses the fixed-resource situation is seen as one which does not normally change over the short term. The second step comprises the identification of the variable resources which are dependent on the resource structure determined in step one. In the third instance certain data for a RF are required in order to do economic analyses which are not necessarily typical of a specific RF, but which might apply to the area. For instance, typical debt ratios which do not correlate with the different RFs might apply to the area as a whole. The final step includes taking into account management decisions such as the area allotted to each crop.

This procedure was followed as described and the four steps are dealt with in this chapter.

### 1.3.1 Research area

Names and addresses of the farmers in the Winterton irrigation area were obtained from the co-operative. From these lists 53 irrigation farmers were identified during the first survey. Although there are nine more irrigation farmers in the area, the 53 farmers were all that were available at the time of the first survey. There are three irrigation boards in the area which serve the different irrigation localities. These localities are in the vicinity of the Little Tugela River, Sterkspruit and Lindequespruit.

### 1.3.2 Data collection

#### 1.3.2.1 Fixed resources

Step one of the procedure comprises the compilation of physical data dealing with land area owned in terms of natural veld, irrigation and dry-lands, water quotas, the type of irrigation and the type of livestock enterprises. Questionnaires were completed by means of personal interviews with the different farmers. The nature of the questionnaire as well as the fact that as many irrigation farmers as possible had to be involved in the formulation of suitable RFs, led to the choice of personal interviews as the method used. This questionnaire was combined with a questionnaire which determined the farmers' attitudes, views and management reactions with respect to variability in the agricultural sector. Also included, was a section which dealt with the third step in the procedure, namely the socioeconomic information on the area. In this chapter only the sections of the questionnaire relating to the formulation of RFs are concentrated on.

The section of the questionnaire which deals with the fixed-resource situation consists of 13 questions. The only biographical questions deal, with the farmer's age and telephone number. The other questions concern farming experience, type of business, sources of water supply, highest and lowest pump levels and whether farmers have a non-farming source of income. The farmers also had to indicate the area of irrigated lands, dry-lands and natural veld they owned or rented. Furthermore they had to indicate to which crops, livestock enterprises and cultivated pastures these areas were allotted, as well as the size of the livestock enterprises. Finally the farmers had to indicate which methods of irrigation they employ, as well as the areas irrigated with each method.

These questionnaires were completed by all 53 farmers. Fifty of the 53 questionnaires could be used, which constitute 94 % of the farmers. Three questionnaires were not properly completed and could not be used.

#### 1.3.2.2 Variable resources

The fixed-resource data were analyzed and based on the results, the RFs were identified. Afterwards group discussions were held to determine the variable-resource situation, which is dependent on the fixed-resource situation, for every RF. These group discussions were held with farmers who found themselves within the specified fixed-resource situation. Two sessions were held which were attended by two and three farmers respectively.

*The questionnaire consists of seven sections. In the first section, the fixed-resource* situation is explained to farmers. This division comprises the areas, locality, soil type, water quota, pump level and type of livestock. The second and third sections deal with the type of crops and livestock quantity. After that attention is given to the number of tractors and implements needed for cultivating the crops. The next three sections deal with labour, buildings and cost of living. In the last section economic and technical coefficients which have cost implications for the implements in the mechanization system, are collected. The questionnaire was discussed with the farmers with the help of an overhead projector.

#### 1.3.2.3 Financial data

The socioeconomic part of the questionnaire referred to in section 1.3.2.1, is divided into three questions which deal with equity, liabilities and gross income of the farmers. Relatively small intervals were specified in every question and the farmers were requested to indicate the intervals applicable to them. Additional socioeconomic information was obtained from the co-operative. The co-operative supplied balance-sheet information for 21 farmers on an anonymous basis. A possible reason why information for so few farmers was supplied, could be that the co-operative only has information for farmers who applied for production loans.

#### 1.3.2.4 *Management decisions*

The management decisions that have to be made before economic analyses can be done, include decisions on area assigned to the various crops as well as the production systems and practices to be used. Some of this information was obtained from the section on variable resources, where the farmers had to indicate which crops are cultivated as well as the most commonly used crop-rotation system. They were also requested to indicate the most common livestock enterprises found in the Winterton irrigation area.

### 1.3.3 Processing and analysis of data

#### 1.3.3.1 Fixed resources

Data from all the questionnaires were verified and, where necessary, the correct information was obtained and corrections made. After that, the data were analyzed with respect to the basic statistics, using a personal computer running the statistical program CSS. Frequency distributions of all the data were then drawn up and analyzed with the help of DBase IV. Frequency intervals differed between the variables. A frequency distribution with a zero value as well as an unlimited value was included for every variable, except in the case of multiple choice questions where the number of people choosing the different options, were counted.

#### 1.3.3.2 Variable resources

Since the data obtained by the questionnaires needed no processing a list reflecting all the variable resources needed in every RF, was compiled.

#### 1.3.3.3 Financial data

It was decided to use both sets of data since they complement each other and no significant differences occur. Once again the statistical analyses were done on a personal computer running the CSS program. The data were read into DBase IV, frequency distributions were drawn up and the data were analyzed.

#### 1.3.3.4 Management decisions

The most important cash crops for the Winterton area were identified, after which the most frequently used crop-rotation system was determined. The livestock enterprises which are most often found in the area were pointed out in the variable resource analyses. This clarified the situation regarding the management of irrigation land, especially drag lines. This management includes aspects such as the type of cultivated pastures as well as its utilization.

## 1.4 RESULTS AND DISCUSSION OF RESULTS

The results obtained in the formulation of RFs are discussed according to the fixed-resource situation, variable-resource situation, socioeconomic situation and the management situation of RFs in the Winterton irrigation area.

### 1.4.1 Fixed-resource situation of representative farms in the Winterton area

The fixed-resource situation can be seen as a situation which would not normally change within one year and includes areas owned under irrigation, dry-land crops and natural veld as well as the type of irrigation, water quotas and livestock enterprises. These results are presented in three sections. In the first section a short summary of the basic statistics is given. The second section comprises the frequency tables and thirdly the RFs are defined in terms of the fixed-resource situation.

### 1.4.1.1 Basic statistics

Table 1.1 shows the summarized basic statistics of the 50 irrigation farmers in the Winterton area. The farmers' ages vary from 24 to 71 years, whereas farming experience varies from 2 to 42 years, with an average of 19 years. From the coefficient of variance and the skewness of the distributions it becomes clear that substantial variance occurs in the variables.

Table 1.1 Summarized statistics (minimum, maximum, average, standard deviation, coefficient of variance, skewness and curtosis) for the variables of the accumulated physical data of 50 farmers in the Winterton irrigation area, 1993

| DISTRIBUTION | MINIMUM | MAXIMUM | AVERAGE | STANDARD DEVIATION | COEFFICIENT OF VARIANCE | SKEWNESS | CURTOSIS |
|---|---|---|---|---|---|---|---|
| Age | 24 | 71 | 45,36 | 11,17 | 24,63 | 0,10 | -0,67 |
| Experience | 2 | 42 | 19,46 | 10,57 | 54,32 | 0,24 | -0,83 |
| **Area** | | | | | | | |
| Own irrigation land | 0 | 320 | 97,63 | 85,00 | 89,19 | 0,88 | -0,20 |
| Rented irrigation land | 0 | 80 | 6,21 | 13,05 | 336,34 | 4,34 | 21,88 |
| Total irrigation | 10 | 320 | 103,84 | 84,70 | 81,57 | 0,79 | -0,40 |
| Own veld | 0 | 5600 | 442,44 | 970,85 | 222,74 | 3,76 | 16,04 |
| Veld rented | 0 | 1500 | 103,84 | 265,96 | 274,70 | 3,54 | 14,61 |
| Total veld | 0 | 5600 | 545,84 | 1068,70 | 195,79 | 3,20 | 10,99 |
| Own dry-lands | 0 | 730 | 89,12 | 126,34 | 140,66 | 2,88 | 11,71 |
| Dry-lands rented | 0 | 225 | 25,34 | 54,59 | 209,64 | 2,36 | 5,23 |
| Total dry-lands | 0 | 730 | 114,46 | 132,64 | 115,88 | 2,22 | 7,52 |
| Total farm size | 0 | 6160 | 629,19 | 1048,24 | 166,09 | 3,56 | 15,04 |
| **Irrigation area** | | | | | | | |
| Centre pivot | 0 | 320 | 62,74 | 79,00 | 125,92 | 1,24 | 0,89 |
| Drag line | 0 | 110 | 26,20 | 25,10 | 95,80 | 1,22 | 1,32 |
| Flood | 0 | 22 | 0,78 | 3,53 | 452,56 | 4,88 | 25,76 |
| Side roll | 0 | 46 | 3,96 | 10,45 | 263,89 | 2,81 | 7,99 |
| Canon | 0 | 45 | 4,32 | 11,04 | 255,56 | 2,51 | 5,70 |
| Other | 0 | 46 | 1,54 | 7,69 | 499,35 | 4,87 | 24,16 |
| **Crop cultivation** | | | | | | | |
| Dry-land cash crops | 0 | 280 | 79,70 | 79,64 | 99,92 | 0,87 | -0,19 |
| Dry-land cultivated pastures | 0 | 200 | 9,12 | 37,16 | 407,46 | 4,04 | 16,43 |
| Irrigation cash crops | 0 | 480 | 91,68 | 116,48 | 127,05 | 1,31 | 1,24 |
| Irrigated cultivated pastures | 0 | 131 | 26,28 | 30,99 | 117,92 | 1,06 | 0,85 |

With the exception of age, experience and total irrigation, the minimum value for all variables is zero whereas maximum values are very high. In the case of own grazing land, for instance, the maximum value is 5 600 which gives an indication of the large variance in the variable. This variance is applicable to all the variables and is especially reflected in the large values of the standard deviation. In all cases the variables are positively skew which implies that lower frequency intervals will, in general, show higher frequencies. The curtosis indicates the peak of the distributions. Here, too, the variables differ to a large extent with the irrigation area under flood irrigation showing a relatively peaked distribution, whereas the total irrigation area shows a reasonably flat distribution.

#### 1.4.1.2 Frequency distribution of variables at farm level

In Table 1.2 the frequency distribution of own, rented and total irrigation land is shown. There will, however, be concentrated on own land only since rented land is seen as a variable resource which can change from one year to the next. An interval size of 50 ha was chosen because this is the size that is most often encountered in practice. If 50 ha is chosen as the central value it means that land belonging to farmers who fall in this interval will not deviate by more than 25 ha. Therefore farmers can identify themselves with such an interval.

Table 1.2 Frequency distribution of the size of own, rented and total irrigation land for the irrigation farmers in the Winterton area, 1993

| IRRIGATION LAND (ha) | OWN | | RENTED | | TOTAL | |
|---|---|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| 0 | 1 | 2 | 43 | 86 | 0 | 0 |
| 1 - 25 | 8 | 16 | 4 | 8 | 7 | 14 |
| 26 - 75 | 17 | 34 | 2 | 4 | 18 | 36 |
| 76 - 125 | 9 | 18 | 1 | 2 | 10 | 20 |
| 126 - 175 | 1 | 2 | 0 | 0 | 1 | 2 |
| 176 - 225 | 9 | 18 | 0 | 0 | 9 | 18 |
| > 225 | 5 | 10 | 0 | 0 | 5 | 10 |
| TOTAL | 50 | 100 | 50 | 100 | 50 | 100 |

From the table it is clear that the four intervals with central values of 12.5, 50, 100 and 200 ha show the highest frequencies. These four intervals represent 86 % of the farmers, while the rest are reasonably dispersed.

It was decided to use only central values of 50, 100 and 200 ha as typical areas for irrigation land. The first interval serves only as a dividing point between areas which justify economic analysis and those that don't. These three areas represent 70 % of the farmers and should provide reasonably diverse economic and financial results.

Frequency distributions were prepared for the different methods of irrigation. This showed that most farmers own drag line irrigation, mainly because of the small areas they irrigate. Centre pivots also form an important part of the irrigation systems, while the other systems are not representative at all. Thirty-two percent of the farmers don't cultivate cash crops under irrigation, while 44 % of them cultivate pastures. The large numbers of farmers who do not cultivate cash crops and who plant cultivated pastures can be ascribed to the large number of small areas under irrigation. Of the 50 farmers, ten irrigate from the Sterkspruit, nine from the canal and five from the Little Tugela River. The rest of the farmers utilize more than one source of water, which include farm dams and the Lindequespruit.

Table 1.3 Frequency distribution of the ratio of centre pivot irrigation to drag line irrigation for the 17 irrigation farmers in the Winterton area with ± 50 ha irrigation land, 1993

| DISTRIBUTION (%) | CENTRE PIVOT IRRIGATION | | DRAG LINE IRRIGATION | |
|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| 0 | 13 | 76,4 | 5 | 29,4 |
| 1 - 5 | 0 | 0,0 | 0 | 0,0 |
| 6 - 10 | 0 | 0,0 | 1 | 5,9 |
| 11 - 15 | 0 | 0,0 | 1 | 5,9 |
| 16 - 20 | 0 | 0,0 | 0 | 0,0 |
| 21 - 25 | 0 | 0,0 | 0 | 0,0 |
| 26 - 30 | 0 | 0,0 | 1 | 5,9 |
| 31 - 35 | 0 | 0,0 | 0 | 0,0 |
| 36 - 40 | 1 | 5,9 | 0 | 0,0 |
| 41 - 45 | 0 | 0,0 | 1 | 5,9 |
| 46 - 50 | 0 | 0,0 | 1 | 5,9 |
| 51 - 55 | 0 | 0,0 | 0 | 0,0 |
| 56 - 60 | 0 | 0,0 | 1 | 5,9 |
| 61 - 65 | 0 | 0,0 | 0 | 0,0 |
| 66 - 70 | 0 | 0,0 | 0 | 0,0 |
| 71 - 75 | 1 | 5,9 | 0 | 0,0 |
| 76 - 80 | 0 | 0,0 | 0 | 0,0 |
| 81 - 85 | 0 | 0,0 | 1 | 5,9 |
| 86 - 90 | 1 | 5,9 | 0 | 0,0 |
| 91 - 95 | 0 | 0,0 | 0 | 0,0 |
| 96 - 100 | 1 | 5,9 | 5 | 29,3 |
| TOTAL | 17 | 100,0 | 17 | 100,0 |

The ratio within which the farmers use the two most important irrigation methods should, however, be determined. The ratio of centre pivot irrigation to drag line irrigation for the different farmers whose irrigation areas fall within the modal intervals with central values of 50, 100 and 200 ha, are given in Tables 1.3 to 1.5.

Table 1.4 Frequency distribution of the ratio of centre pivot irrigation to drag line irrigation for the 9 irrigation farmers in the Winterton area with ± 100 ha irrigation land, 1993

| DISTRIBUTION (%) | CENTRE PIVOT IRRIGATION | | DRAG LINE IRRIGATION | |
|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| 0 | 1 | 11,2 | 0 | 0,0 |
| 1 - 5 | 0 | 0,0 | 0 | 0,0 |
| 6 - 10 | 0 | 0,0 | 2 | 22,3 |
| 11 - 15 | 0 | 0,0 | 0 | 0,0 |
| 16 - 20 | 0 | 0,0 | 0 | 0,0 |
| 21 - 25 | 0 | 0,0 | 0 | 0,0 |
| 26 - 30 | 0 | 0,0 | 1 | 11,1 |
| 31 - 35 | 0 | 0,0 | 1 | 11,1 |
| 36 - 40 | 0 | 0,0 | 2 | 22,2 |
| 41 - 45 | 0 | 0,0 | 1 | 11,1 |
| 46 - 50 | 2 | 22,2 | 1 | 11,1 |
| 51 - 55 | 0 | 0,0 | 1 | 11,1 |
| 56 - 60 | 2 | 22,2 | 0 | 0,0 |
| 61 - 65 | 1 | 11,1 | 0 | 0,0 |
| 66 - 70 | 0 | 0,0 | 0 | 0,0 |
| 71 - 75 | 0 | 0,0 | 0 | 0,0 |
| 76 - 80 | 2 | 22,2 | 0 | 0,0 |
| 81 - 85 | 0 | 0,0 | 0 | 0,0 |
| 86 - 90 | 1 | 11,1 | 0 | 0,0 |
| 91 - 95 | 0 | 0,0 | 0 | 0,0 |
| 96 - 100 | 0 | 0,0 | 0 | 0,0 |
| TOTAL | 9 | 100,0 | 9 | 100,0 |

In the case of the 50 ha irrigation land, 76,4 % of the farmers do not have any centre pivot systems while 70,6 % of the farmers do have drag line systems. The total area is therefore taken as drag line irrigation. The farmers with 100 ha of irrigation land have a good distribution between centre pivot and drag line systems. Farmers with drag line systems are concentrated in the vicinity of 25 to 55 %, with the greater concentration between 36 and 40 %. Farmers with centre pivot systems range from 46 %, with a concentration at the two intervals from 56 to 65 %. The 100 ha irrigation land is therefore considered as 60 ha (60 %) centre pivot and 40 ha (40 %) drag line irrigation. In the case of the 200 ha irrigation land, a concentration of farmers are found in the 81 to 90 % interval as well as the 96 to 100 % interval. Drag line irrigation farmers are found in the vicinity of the 11 to 15 % interval. The 200 ha irrigation land is therefore considered as 170 ha (85 %) centre pivot and 30 ha (15 %) drag line irrigation.

Table 1.5 Frequency distribution of the ratio of centre pivot irrigation to drag line irrigation for the 9 irrigation farmers in the Winterton area with ± 200 ha irrigation land, 1993

| DISTRIBUTION (%) | CENTRE PIVOT IRRIGATION | | DRAG LINE IRRIGATION | |
|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| 0 | 0 | 0,0 | 2 | 22,2 |
| 1 - 5 | 0 | 0,0 | 1 | 11,1 |
| 6 - 10 | 0 | 0,0 | 0 | 0,0 |
| 11 - 15 | 0 | 0,0 | 3 | 33,4 |
| 16 - 20 | 1 | 11,1 | 0 | 0,0 |
| 21 - 25 | 0 | 0,0 | 0 | 0,0 |
| 26 - 30 | 0 | 0,0 | 1 | 11,1 |
| 31 - 35 | 0 | 0,0 | 0 | 0,0 |
| 36 - 40 | 0 | 0,0 | 0 | 0,0 |
| 41 - 45 | 0 | 0,0 | 0 | 0,0 |
| 46 - 50 | 1 | 11,1 | 1 | 11,1 |
| 51 - 55 | 0 | 0,0 | 0 | 0,0 |
| 56 - 60 | 1 | 11,1 | 0 | 0,0 |
| 61 - 65 | 0 | 0,0 | 1 | 11,1 |
| 66 - 70 | 0 | 0,0 | 0 | 0,0 |
| 71 - 75 | 0 | 0,0 | 0 | 0,0 |
| 76 - 80 | 0 | 0,0 | 0 | 0,0 |
| 81 - 85 | 1 | 11,1 | 0 | 0,0 |
| 86 - 90 | 2 | 22,2 | 0 | 0,0 |
| 91 - 95 | 0 | 0,0 | 0 | 0,0 |
| 96 - 100 | 3 | 33,4 | 0 | 0,0 |
| TOTAL | 9 | 100,0 | 9 | 100,0 |

Table 1.6 indicates the frequency distribution of own, rented and total dry-lands. Once again intervals of 50 ha are used, which cause that farmers won't deviate from the central point with more than 25 ha.

A large number of the farmers (44 %) have 25 ha and less dry-lands. The three intervals with central values of 50, 100 and 150 ha represent 44 % of the farmers. The rest of the farmers are divided equally between the remaining intervals. In the case of dry-lands 80 % of the farmers cultivate cash crops. The remaining 20 % are mainly used for cultivated pastures.

Intervals with central values of 50 and 150 ha are chosen. The interval with a central value 100 ha is omitted since it will probably provide economic and financial results with values in between the values of the 50 and 150 ha areas. A situation with no dry-lands is also included. If the farmers with 25 ha and smaller can associate themselves with the 0 or the 50 ha, then 76 % of the farmers can associate themselves with the three situations.

Table 1.6 Frequency distribution of the size of own, rented and total dry-lands for the irrigation farmers in the Winterton area, 1993

| DRY-LAND (ha) | OWN | | RENTED | | TOTAL | |
|---|---|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| 0 | 13 | 26 | 34 | 68 | 7 | 14 |
| 1 - 25 | 9 | 18 | 5 | 10 | 10 | 20 |
| 26 - 75 | 7 | 14 | 5 | 10 | 7 | 14 |
| 76 - 125 | 6 | 12 | 3 | 6 | 7 | 14 |
| 126 - 175 | 9 | 18 | 0 | 0 | 9 | 18 |
| 176 - 225 | 2 | 4 | 3 | 6 | 2 | 4 |
| 226 - 275 | 2 | 4 | 0 | 0 | 4 | 8 |
| > 275 | 2 | 4 | 0 | 0 | 4 | 8 |
| TOTAL | 50 | 100 | 50 | 100 | 50 | 100 |

The frequency distribution of own, rented and total natural veld are shown in Table 1.7. The frequency intervals are 200 ha, with the result that farmers do not deviate from the central value with more than 100 ha. Only own grazing land is considered, since rented land is considered to be variable. From the table it can be deduced that a large number of farmers (52 %) own less than 100 ha of natural veld, or none at all. A further 28 % of the farmers own between 100 and 500 ha of natural veld, while there is a reasonable distribution of farmers over the rest of the areas.

Table 1.7 Frequency distribution of the size of own, rented and total natural veld for the irrigation farmers in the Winterton area, 1993

| NATURAL VELD (ha) | OWN | | RENTED | | TOTAL | |
|---|---|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| 0 | 5 | 10 | 37 | 74 | 4 | 8 |
| 1 - 100 | 21 | 42 | 4 | 8 | 20 | 40 |
| 101 - 300 | 8 | 16 | 3 | 6 | 7 | 14 |
| 301 - 500 | 6 | 12 | 3 | 6 | 5 | 10 |
| 501 - 700 | 3 | 6 | 1 | 2 | 4 | 8 |
| 701 - 900 | 2 | 4 | 1 | 2 | 4 | 8 |
| 901 -1 100 | 1 | 2 | 0 | 0 | 2 | 4 |
| >1 100 | 4 | 8 | 1 | 2 | 4 | 8 |
| TOTAL | 50 | 100 | 50 | 100 | 50 | 100 |

For the purposes of the research it was decided to include the two intervals with central values of 200 and 400 ha as one. This decision stems from the fact that large economical differences are not expected to be found between the two intervals. In this way 28 % of the farmers are included and a joint central value of 300 ha is found where farmers' values won't deviate more than 200 ha from the central value. Together with this interval an interval with a zero value is also included. Assuming that 52 % of the farmers can identify with the zero value, 80 % of the farmers who can identify with both distributions are included.

The farm businesses in the Winterton irrigation area are very diversified, with the result that different combinations of livestock enterprises are found as well as different types of livestock enterprises. Nevertheless it is clear that beef- and dairy herds can be considered to be the most important livestock enterprises, counting 20 and 14 % respectively and, in combination, a further 12 %. The livestock enterprise distribution of the 14 farmers counted in the 300 ha natural veld interval is shown in Table 1.8. From the table it can be seen that ten of the farmers keep dairy cattle and nine of them have beef cattle. It can therefore be said with reasonable certainty that 300 ha of the natural veld carries beef cattle and dairy cattle. It is also clear that different combinations of livestock enterprises are found, which once again underlines the diversity of the farm businesses in the area.

Table 1.8 Distribution of each type of livestock as stocked by 14 irrigation farmers with ± 300 ha veld in the Winterton area, 1993

| TYPE OF LIVESTOCK | NUMBER OF FARMERS | TOTAL NUMBER OF FARMERS | % |
|---|---|---|---|
| Mutton breeds | 1 | 14 | 7,1 |
| Dual purpose sheep | 4 | 14 | 28,6 |
| Dairy cattle | 10 | 14 | 71,4 |
| Beef cattle | 9 | 14 | 64,3 |
| Chickens | 2 | 14 | 14,3 |
| Hogs | 4 | 14 | 28,6 |

### 1.4.1.3 Representative farms

The main criteria for the composition of representative farms are the areas irrigated, natural veld and dry-lands. In Table 1.9 the frequency distributions of natural veld and dry-lands within the framework of the three specified irrigation areas of 50, 100 and 200 ha which form the basis for the formulation of the RFs, are shown. It must be taken into account that, in the case of natural veld, the two intervals (101-300 and 301-500) are taken as one interval. Natural veld is included as follows: (1) 0 to 300 ha with 50 ha irrigation; (2) 0 ha with 100 ha irrigation; and (3) 0 and 300 ha with 200 ha irrigation. Dry-lands are included as follows: (1) 0 and 150 ha with 50 ha irrigation; (2) 0 ha with 100 ha irrigation; and (3) 0 and 50 ha with 200 ha irrigation. No correlation was found between the different areas, with the result that any combination could be included.

Table 1.10 contains nine RFs for the Winterton area. According to personal accounts from farmers they are agreed that all the RFs under drag line irrigation are used for cultivated pastures. In the case of the 50 ha irrigation land, irrigation is done by means of drag lines and the 300 ha veld is utilized by beef cattle, whereas the cultivated pastures is utilized by both dairy and beef enterprises. Forty hectares of the 100 ha irrigation land is irrigated by means of drag lines, which are utilized for cultivating pastures for the dairy cattle enterprises. The 200 ha irrigation are divided in 170 ha centre pivot irrigation and 30 ha drag line irrigation. The 300 ha cultivated pastures is utilized by beef cattle and the 30 ha cultivated pastures under drag line irrigation, is utilized by beef and dairy enterprises.

Table 1.9 Frequency distributions of veld and dry-lands which fall within the three types of frequency distributions of irrigation land for the irrigation farmers in the Winterton area, 1993

| IRRIGATION LAND | | | VELD | | | DRY-LAND | | |
|---|---|---|---|---|---|---|---|---|
| TYPICAL FREQUENCY-DISTRIBUTIONS | NUMBER OF FARMERS | % | TYPICAL FREQUENCY-DISTRIBUTIONS | NUMBER OF FARMERS | % | TYPICAL FREQUENCY-DISTRIBUTIONS | NUMBER FARMERS | % |
| 26 - 75 | 17 | 100 | 1 - 100 | 9 | 53 | 1 - 25 | 8 | 47 |
| | | | 101 - 300 | 2 | 12 | 26 - 75 | 3 | 18 |
| | | | 301 - 500 | 4 | 24 | 126 - 175 | 3 | 18 |
| 76 - 125 | 9 | 100 | 1 - 100 | 6 | 67 | 1 - 25 | 7 | 78 |
| | | | 101 - 300 | 1 | 11 | 26 - 75 | 0 | 0 |
| | | | 301 - 500 | 1 | 11 | 126 - 175 | 1 | 11 |
| 176 - 225 | 9 | 100 | 1 - 100 | 3 | 33 | 1 - 25 | 3 | 33 |
| | | | 101 - 300 | 2 | 22 | 26 - 75 | 3 | 33 |
| | | | 301 - 500 | 1 | 11 | 126 - 175 | 1 | 11 |

### 1.4.2 Variable-resource situations of representative farms in the Winterton area

The variable-resource situation on a RF depends on the fixed-resource structure of the relevant RF (Meiring and Oosthuizen, 1993:49). Variable resources can be defined as a resource situation which can change within one year. It comprises the mechanization systems, livestock and labour requirements.

Kletke and Sestak (1990), as quoted by Meiring and Oosthuizen (1993:52) point out that farmers often invest more in machines than in any other agricultural assets. This statement is largely applicable to most irrigation farming, especially if the irrigation systems are considered to be machinery.

During group discussions it became clear that the number and types of implements are determined by the areas under cultivation, the type of crops cultivated as well as the crop-rotation systems which are followed. Especially some crop-rotation systems compel farmers to fight against time. This often leads to over capitalization.

Table 1.10 Nine representative farms in the Winterton irrigation area, as defined by the typical fixed-resource situation, 1993

| RF | IRRIGATION AREA | | | VELD (ha) | DRY-LAND (ha) | LIVESTOCK |
|---|---|---|---|---|---|---|
| | TOTAL (ha) | CENTRE PIVOT (ha) | DRAG LINE (ha) | | | |
| 1 | 50 | 0 | 50 | 0 | 0 | Dairy cattle |
| 2 | 50 | 0 | 50 | 0 | 150 | Dairy cattle |
| 3 | 50 | 0 | 50 | 300 | 0 | Dairy cattle/beef cattle |
| 4 | 50 | 0 | 50 | 300 | 150 | Dairy cattle/beef cattle |
| 5 | 100 | 60 | 40 | 0 | 0 | Dairy cattle |
| 6 | 200 | 170 | 30 | 0 | 0 | Dairy cattle |
| 7 | 200 | 170 | 30 | 0 | 50 | Dairy cattle |
| 8 | 200 | 170 | 30 | 300 | 0 | Dairy cattle/beef cattle |
| 9 | 200 | 170 | 30 | 300 | 50 | Dairy cattle/beef cattle |

In Table 1.11 typical mechanization systems for 50 ha with no dry-lands, 50 ha with dry-lands, 100 and 200 ha irrigation areas are given. The extra machinery needed for the cultivation of the dry-lands, if any, are also included. During group discussions farmers agreed that areas under drag line irrigation are mainly used for the cultivation of pastures. Cash crops cultivated under centre pivot irrigation consist mainly of maize, wheat and soybeans. On the dry-lands only maize is cultivated. Although the farmers with 100 and 200 ha irrigation land harvest and transport their own crops they also make use of contractors, mainly to clear the lands in time for the next crop.

The value for each of the mechanization systems, taken at market value, amount to R123 100 for the 19 implements of the 50 ha irrigation land without dry-lands, R230 400 for the 31 implements of the 50 ha irrigation land with dry-lands, R380 400 for the 36 implements of the 100 ha irrigation land and R384 400 for the 38 implements of the

200 ha irrigation land. The market values were determined during the group discussions and do not include the irrigation systems. The replacement value of each system will

Table 1.11 Mechanization system needed by representative farms with 50 ha of irrigation land with no dry-lands, 50 ha of irrigation land with dry-lands and 100 ha and 200 ha of irrigation land in the Winterton area, 1993

| TYPE OF IMPLEMENT | NUMBER OF IMPLEMENTS | | | |
|---|---|---|---|---|
| | 50 ha WITHOUT DRY-LANDS | 50 ha WITH DRY-LANDS | 100 ha | 200 ha |
| Tractor: 45 kW | 1 | - | - | - |
| 52 kW | 1 | 1 | - | 1 |
| 60 kW | 1 | 2 | 2 | 2 |
| 72 kW | 1 | 2 | 1 | - |
| 103 kW | - | - | 2 | 2 |
| Self propelled harvester | - | - | 1 | 1 |
| Water cart: 4 ton | - | 1 | 1 | 1 |
| Trailer: 4 ton | 1 | - | - | - |
| 8 ton | 1 | 2 | 2 | 2 |
| Water cart: 1 000 l | - | - | - | 1 |
| Mouldboard plough: 3 furrow | 1 | 1 | - | 1 |
| 4 furrow | - | 1 | 2 | - |
| Disc harrow: 2,5 m | 1 | - | - | 2 |
| 3,0 m | - | 1 | 1 | - |
| Ripper plough: 3 tine | 1 | - | - | - |
| 5 tine | - | - | - | 2 |
| Chisel plough: 5 tine | - | 1 | 1 | - |
| 9 tine | - | 1 | 1 | 1 |
| Row crop cultivator | - | 2 | 2 | 2 |
| Multi-purpose cultivator | - | 1 | 1 | 1 |
| Mulcher | - | - | - | 1 |
| Land roller | 1 | 1 | 1 | 1 |
| Spike tooth harrow | - | 1 | 1 | 1 |
| Rotary harrow | - | 1 | 1 | 1 |
| Maize planter | - | 1 | 1 | 1 |
| Wheat planter | - | - | 1 | 1 |
| Fertilizer spreader: 600 l | 1 | 1 | 1 | 1 |
| Lime spreader: 3 ton | - | - | 1 | - |
| 5 ton | - | - | - | 1 |
| Boom sprayer: 600 l | 1 | 1 | 1 | - |
| 1 500 l | - | - | - | 1 |
| Hammer mill | 1 | 1 | 1 | 1 |
| Feed mixer | 1 | 1 | 1 | 1 |
| Mower: 1,5 m drum | 1 | 1 | 1 | 1 |
| Hay rake: 4 wheel | 1 | 1 | 1 | 1 |
| Baler: 1,2 m round | 1 | 1 | 1 | 1 |
| Loading fork | 1 | 1 | 1 | 1 |
| Silage cutter | - | 1 | 1 | 1 |
| Front end loader | - | - | 1 | - |
| LDV | 1 | 1 | 2 | 2 |
| Lorry | - | 1 | 1 | 1 |

however be considerably higher. Furthermore, it becomes clear that the larger farmers enjoy advantages of scale because the values of the mechanization systems do not increase at the same rate as the areas.

The typical family for all the RFs comprises five people. The farmers also agree that their cost of living amounts to about R55 000/year.

The farmers with 50 and 100 ha under irrigation use 20 labourers, while the farmers with 200 ha under irrigation use 30 labourers. In all three cases the cash wages of labourers vary between R150 and R200/month. It is important to note that farmers do not employ additional labourers if they own a beef herd. Casual labour is employed at harvest time. Twenty casual labourers are usually employed for a period of 120 days at R6/day.

The three cases of RFs each has a homestead, a milk shed and out-buildings. The total value of the buildings amounts to between R360 000 and R380 000.

Tables 1.12 and 1.13 describe the beef cattle and dairy enterprises which evolved as variable resources from the different RFs. As has been mentioned, the 300 ha natural veld are used for beef cattle, whereas the cultivated pastures are used for beef as well as dairy cattle.

Table 1.12 Description of the beef cattle enterprise on 300 ha veld in the Winterton irrigation area, 1993

| DESCRIPTION | 300 ha |
|---|---|
| Calving percentage | 84 % |
| Mortality rate | 3 % |
| Number of cows | 100 |
| Number of bulls | 4 |
| Annual culling | 20 % |

For the greater part dairy herds consist of Frisian cattle though some farmers do stock Jerseys. No pure breed of beef cattle is found in the area, but Brahman cross-breeds are quite common.

The livestock enterprises are used separately from the crop enterprises. The only interaction between the enterprises occurs when the crop residues are fed to the cattle during the winter months. The cultivated pastures is used in the beef cattle enterprise to raise weaners and to fatten speculation stock.

Table 1.13 Description of the dairy enterprise on 50 ha cultivated pastures in the Winterton irrigation area, 1993

| DESCRIPTION | 50 ha |
|---|---|
| Inter calving period | 390 days |
| Annual culling | 25 % |
| Lactation period | 315 days |
| Lactation cows | 100 |
| Dry cows | 25 |
| Bulls | 1 |
| Calving percentage | 94 % |
| Mortality rate | 10 % |

### 1.4.3 The capital structure in the Winterton area

Although the capital structures of the farmers are not typical of each RF, they are typical of the Winterton area. The results discussed here, are treated under two headings. Firstly, the basic statistics regarding the balance sheet values are discussed followed by the frequency distributions of the balance sheet values.

#### 1.4.3.1 Basic statistics

The basic statistics from the balance sheets of 21 farmers are shown in Table 1.14. All statistics concerning assets are shown at the farmers' valuation (market value) as well as co-operative's valuation (liquidation value).

Some of the farmers have no liabilities. The higher maximum figure for short-term liabilities as compared to long-term liabilities, indicates an unhealthy liability structure in some cases. This situation applies to six of the 21 farmers. From the asset analysis it is obvious that all the farmers own some land. The large differences between liquidation and market values show the important influence of valuation methods on the financial position as portrayed in the balance sheet. The farmers show a minimum net worth of R139 510 as market value of their assets, whereas the more conservative liquidation value indicates a case where a business is insolvent to the amount of R110 740. The large discrepancies between the minimum and maximum values indicate that there are large differences between the farmers' financial situations in the area.

If it is accepted that the 21 farmers reflect the general situation of the 50 farmers in the area whose information were used in the identification of RFs, and if average values are used, then the farmers manage total assets at liquidation value of R68 531 350 and their net worth amounts to R41 427 200. The extent of the capital involved, emphasizes the necessity to manage these assets in the best way possible.

Table 1.14 Enumerative statistics (minimum, maximum, average, standard deviation, coefficient of variance, skewness and curtosis) for the variables of the accumulated physical data of 21 farmers in the Winterton irrigation area, 1993

| DISTRIBUTION | | MINIMUM | MAXIMUM | AVERAGE | STANDARD DEVIATION | COEFFICIENT OF VARIANCE | SKEWNESS | CURTOSIS |
|---|---|---|---|---|---|---|---|---|
| **Liabilities** | | | | | | | | |
| Bank overdraft | | 0 | 395000 | 75738 | 122517 | 1,62 | 1,44 | 1,10 |
| Short-term liabilities | | 0 | 814990 | 210869 | 250912 | 1,19 | 1,13 | 0,35 |
| Medium-term liabilities | | 0 | 405000 | 65100 | 103518 | 1,59 | 1,81 | 3,53 |
| Long-term liabilities | | 0 | 750000 | 294685 | 251875 | 0,85 | 0,09 | -1,36 |
| Total liabilities | | 0 | 1754115 | 570654 | 469071 | 0,82 | 0,67 | 0,10 |
| **Assets** | | | | | | | | |
| Short-term assets | | 0 | 348500 | 154934 | 107404 | 0,69 | 0,17 | -1,05 |
| Medium-term assets | -lv[1] | 15000 | 1863050 | 552422 | 426520 | 0,77 | 1,28 | 2,23 |
| | -mv[2] | 15000 | 2256000 | 757629 | 551722 | 0,73 | 0,91 | 0,74 |
| Long-term assets | -lv | 100000 | 2356600 | 663272 | 462361 | 0,70 | 2,15 | 6,74 |
| | -mv | 400000 | 3645000 | 1228044 | 752702 | 0,61 | 1,49 | 3,20 |
| *Total assets* | -lv | *167500* | *4401675* | *1370627* | *864990* | *0,63* | *1,83* | *5,30* |
| | -mv | 473100 | 6083025 | 2140607 | 1249474 | 0,58 | 1,31 | 2,73 |
| **Own capital** | | | | | | | | |
| Net worth | -lv | -110740 | 4183662 | 828544 | 910668 | 1,10 | 2,26 | 6,86 |
| | -mv | 139510 | 5865012 | 1596191 | 1225800 | 0,77 | 1,91 | 5,06 |

1. lv = liquidation value.
2. mv = market value.

### 1.4.3.2 Frequency distributions of balance sheet values

The ratio of debt to assets determines, to a large extent, the viability of a business in an environment where price, production and financial risks occur (Meiring and Oosthuizen, 1993:57). Tables 1.15 and 1.16 show the ratio of total debt to total farming assets for 21 farmers and 50 farmers respectively. Information for the 21 farmers was obtained from the co-operative and include the market as well as liquidation values, while the information for the 50 farmers was obtained from questionnaires completed by the farmers themselves.

Table 1.15 Frequency distribution of the ratios of total liabilities to total farming assets valued at market value and liquidation value for 21 irrigation farmers in the Winterton area, 1993[3]

| INTERVALS (%) | MARKET VALUE | | LIQUIDATION VALUE | |
|---|---|---|---|---|
| | NUMBER OF FARMERS | PERCENTAGE | NUMBER OF FARMERS | PERCENTAGE |
| ≥ 0 ≤ 10 | 6 | 28,6 | 6 | 28,6 |
| > 10 ≤ 20 | 2 | 9,5 | 0 | 0,0 |
| > 20 ≤ 30 | 2 | 9,5 | 1 | 4,8 |
| > 30 ≤ 40 | 4 | 19,0 | 3 | 14,3 |
| > 40 ≤ 50 | 4 | 19,0 | 2 | 9,5 |
| > 50 ≤ 60 | 1 | 4,8 | 2 | 9,5 |
| > 60 ≤ 70 | 1 | 4,8 | 2 | 9,5 |
| > 70 ≤ 80 | 0 | 0,0 | 2 | 9,5 |
| > 80 ≤ 90 | 1 | 4,8 | 0 | 0,0 |
| > 90 ≤ 100 | 0 | 0,0 | 1 | 4,8 |
| > 100 | 0 | 0,0 | 2 | 9,5 |
| TOTAL | 21 | 100,0 | 21 | 100,0 |

3. Information processed from data obtained from co-operative.

Table 1.16 Frequency distribution of the ratios of total liabilities to total farming assets valued at market value for 50 irrigation farmers in the Winterton area, 1993[4]

| INTERVALS | NUMBER OF FARMERS | PERCENTAGE |
|---|---|---|
| ≥ 0 ≤ 10 | 13 | 26,0 |
| > 10 ≤ 20 | 9 | 18,0 |
| > 20 ≤ 30 | 10 | 20,0 |
| > 30 ≤ 40 | 5 | 10,0 |
| > 40 ≤ 50 | 9 | 18,0 |
| > 50 ≤ 60 | 2 | 4,0 |
| > 60 ≤ 70 | 1 | 2,0 |
| > 70 ≤ 80 | 1 | 2,0 |
| > 80 ≤ 90 | 0 | 0,0 |
| > 90 ≤ 100 | 0 | 0,0 |
| TOTAL | 50 | 100,0 |

4. Information processed from questionnaires completed by farmers.

It is evident from Table 1.15 that the debt:asset ratio of most farmers (28,6 %) is between 0 and 10 %, followed by 14,3 % of the farmers with a ratio of between 30 and 40 %.

Nine and a half percent of the farmers fall in the intervals between 40 and 80 %. Only a small number of farmers showed ratios exceeding 80 %. A debt:asset ratio between 5 and 95 % which represents 28,6 % of the farmers and one between 40 and 60 %, which includes 23,8 % of the farmers, was therefore identified.

According to Table 1.16, 26 % of the farmers fall in the interval 0 to 10 %; 20 % in the interval 20 to 30 %; 18 % in the intervals 10 to 20 % and 40 to 50 %; and 10 % in the interval 30 to 40 %. Very few farmers fall in the intervals above 50 %. If the results of Table 1.16 are taken into consideration, 26 % of the farmers with a debt:asset ratio from 5 to 95 % are included, while 28 % of the farmers with a debt:asset ratio of 40 to 60 % are also included in the Table.

No relation was found between the farmers' debt:asset ratios and their liability structures. Tables 1.17 and 1.18 contain the frequency distributions of the short-, medium- and long-term liabilities for 21 and 50 farmers respectively. From Table 1.17 two groups of farmers can be identified with relation to long-term liabilities. The first group lies at intervals 40 to 50 % and 50 to 60 %, while the second group falls in the intervals 70 to 80 %, 80 to 90 % and 90 to 100 %. If the information is compared to Table 1.18, it is evident that the information for the intervals from 40 to 60 % correspond. Long-term liabilities are therefore included as 50 % in the typical liability structure.

Table 1.17 Frequency distribution of the percentage contributions of short-, medium- and long-term liabilities to total liabilities for 19[5] irrigation farmers in the Winterton area, 1993[6]

| INTERVALS (%) | SHORT-TERM LIABILITIES | | MEDIUM-TERM LIABILITIES | | LONG-TERM LIABILITIES | |
|---|---|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| = 0 | 3 | 15,8 | 8 | 42,1 | 1 | 5,3 |
| > 0 ≤ 10 | 3 | 15,8 | 2 | 10,5 | 2 | 10,5 |
| > 10 ≤ 20 | 1 | 5,3 | 5 | 26,3 | 1 | 5,3 |
| > 20 ≤ 30 | 3 | 15,8 | 1 | 5,3 | 1 | 5,3 |
| > 30 ≤ 40 | 2 | 10,5 | 2 | 10,5 | 1 | 5,3 |
| > 40 ≤ 50 | 2 | 10,5 | 0 | 0,0 | 2 | 10,5 |
| > 50 ≤ 60 | 3 | 15,8 | 0 | 0,0 | 3 | 15,8 |
| > 60 ≤ 70 | 0 | 0,0 | 0 | 0,0 | 1 | 5,2 |
| > 70 ≤ 80 | 0 | 0,0 | 0 | 0,0 | 2 | 10,5 |
| > 80 ≤ 90 | 1 | 5,2 | 0 | 0,0 | 2 | 10,5 |
| > 90 ≤ 100 | 1 | 5,3 | 1 | 5,3 | 3 | 15,8 |
| TOTAL | 19 | 100,0 | 19 | 100,0 | 19 | 100,0 |

5. Two of the 21 farmers have no debts.
6. Information processed from data obtained from the co-operative.

Table 1.18 Frequency distribution of the percentage contributions of short-, medium- and long-term liabilities to total liabilities for 45[7] irrigation farmers in the Winterton area, 1993[8]

| INTERVALS (%) | SHORT-TERM LIABILITIES | | MEDIUM-TERM LIABILITIES | | LONG-TERM LIABILITIES | |
|---|---|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| = 0 | 5 | 11,1 | 21 | 46,6 | 12 | 26,7 |
| > 0 ≤ 10 | 4 | 8,9 | 4 | 8,9 | 1 | 2,2 |
| > 10 ≤ 20 | 7 | 15,6 | 8 | 17,8 | 1 | 2,2 |
| > 20 ≤ 30 | 5 | 11,1 | 4 | 8,9 | 1 | 2,2 |
| > 30 ≤ 40 | 3 | 6,7 | 4 | 8,9 | 3 | 6,7 |
| > 40 ≤ 50 | 7 | 15,5 | 3 | 6,7 | 5 | 11,1 |
| > 50 ≤ 60 | 1 | 2,2 | 0 | 0,0 | 6 | 13,3 |
| > 60 ≤ 70 | 3 | 6,7 | 0 | 0,0 | 5 | 11,1 |
| > 70 ≤ 80 | 1 | 2,2 | 0 | 0,0 | 4 | 8,9 |
| > 80 ≤ 90 | 0 | 0,0 | 0 | 0,0 | 4 | 8,9 |
| > 90 ≤ 100 | 9 | 20,0 | 1 | 2,2 | 3 | 6,7 |
| TOTAL | 45 | 100,0 | 45 | 100,0 | 45 | 100,0 |

7. Five of the farmers have no debts.
8. Information processed from questionnaires completed by farmers.

Table 1.19 Frequency distribution of the percentage contribution of bank overdraft, monthly account, production account and other liabilities to total short-term liabilities for 16[9] irrigation farmers in the Winterton area, 1993[10]

| DISTRIBUTIONS (%) | BANK OVERDRAFT | | MONTHLY ACCOUNT | | PRODUCTION ACCOUNT | | OTHER DEBT | |
|---|---|---|---|---|---|---|---|---|
| | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % | NUMBER OF FARMERS | % |
| = 0 | 5 | 31,2 | 1 | 6,2 | 15 | 93,7 | 10 | 62,5 |
| > 0 ≤ 10 | 1 | 6,2 | 1 | 6,2 | 0 | 0,0 | 4 | 25,0 |
| > 10 ≤ 20 | 1 | 6,3 | 1 | 6,2 | 0 | 0,0 | 1 | 6,3 |
| > 20 ≤ 30 | 1 | 6,3 | 1 | 6,3 | 1 | 6,3 | 0 | 0,0 |
| > 30 ≤ 40 | 3 | 18,7 | 1 | 6,3 | 0 | 0,0 | 0 | 0,0 |
| > 40 ≤ 50 | 0 | 0,0 | 2 | 12,5 | 0 | 0,0 | 0 | 0,0 |
| > 50 ≤ 60 | 2 | 12,5 | 1 | 6,3 | 0 | 0,0 | 0 | 0,0 |
| > 60 ≤ 70 | 1 | 6,3 | 1 | 6,3 | 0 | 0,0 | 0 | 0,0 |
| > 70 ≤ 80 | 0 | 0,0 | 2 | 12,5 | 0 | 0,0 | 1 | 6,2 |
| > 80 ≤ 90 | 0 | 0,0 | 0 | 0,0 | 0 | 0,0 | 0 | 0,0 |
| > 90 ≤ 100 | 2 | 12,5 | 5 | 31,2 | 0 | 0,0 | 0 | 0,0 |
| TOTAL | 16 | 100,0 | 16 | 100,0 | 16 | 100,0 | 16 | 100,0 |

9. Five of the 21 farmers have no short-term liabilities.
10. Information processed from data obtained from co-operative.

The short-term liabilities in Table 1.17 centre around the intervals from 0 to 10 % and from 20 to 60 %. In Table 1.18 the short-term liabilities centre around intervals 10 to 30 % and 40 to 50 %. If both tables are taken into account, the short-term liability can be included as 40 % in the typical liability structure. If long-term liabilities constitute 50 % and short-term liabilities 40 %, then medium-term liabilities have to be taken as 10 %. Table 1.17 indicates that 26,3 % of the farmers are included with long-term liabilities of 50 %, 36,8 % of the farmers are included with medium-term liabilities of 10 and 21 % of the farmers with short-term liabilities of 40 %.

Table 1.19 gives the distribution of short-term liabilities. These vary over the short term. From the information it would seem that the majority of the farmers do not use production loans, but only overdrafts and monthly accounts. The situation varies from one producer to the next as well as from one season to the next. For the majority of producers as on September 1992, bank overdrafts constitute 30 % of short-term liabilities and co-operative monthly accounts 70 %.

### 1.4.4 MANAGEMENT BEHAVIOUR IN THE WINTERTON AREA

The fourth and final step in the formulation of RFs is the observance of management decisions.

The types and areas of crops under cultivation, as well as the production systems and practices used, are included in these management decisions.

The management decisions can be classified into two types. The first type deals with current decisions which are already implemented. The second type deals with the formulation of alternative management decisions for economic analyses. In this section only the first type will be dealt with, in terms of cash crops produced, livestock enterprises and cultivated pastures.

#### 1.4.4.1 Cash crops

The practice of mono culture is followed in dry-land conditions. In summer the total area is devoted to the cultivation of maize and in winter it lies fallow. During the winter months the crop residue is fed to livestock. This crop-rotation system limits land utilization to 100 % per year.

Cash crops cultivated under irrigation are maize, soybeans and wheat. In summer two thirds of the area is used for maize cultivation and one third for soybeans. Directly after the maize crop has been taken off half the area that was used for maize and therefore one third of the total area, is planted with wheat. The rest of the lands (66,7 %) lie fallow during the winter months. At the end of winter the area used for wheat cultivation, is then used for soybeans. This crop-rotation system results in land utilization of 133,3 %.

#### 1.4.4.2 Livestock enterprises

Farmers with ± 300 ha of natural veld agree that this is large enough to stock a 100-cow beef cattle herd. From this it can be deduced that the carrying capacity of the veld is 3 ha per LSU. During the winter months the maize crop residue is used for the livestock. The bulls are put in with the cows from August up to mid October and from mid November until the end of January. This results in a calving period which lasts from the beginning of June to the end of July as well as one from the beginning of September to the end of October. Twenty-five of the heifers are kept as replacements and the rest of the calves are weaned at the age of seven months. During the weaning period they are kept on cultivated pastures from where they are moved to feeding-pens before being sold. Of the 25 heifers kept for replacements only 20 are eventually needed to replace old cows. The other five are sold. Four bulls are kept for the herd of 100 cows. One of these is replaced every year. To maximize the use of cultivated pastures and the maize crop residue, speculation cattle are bought, fattened and sold. These cattle can be seen as being additional to the existing herd. The maize crop residue and the cultivated pastures have a carrying capacity of one LSU per hectare.

The representative size dairy cattle enterprise is taken at 100 cows in milk. Every year 25 % of the cows are replaced by calves born from the herd and raised on the farm. One bull which is replaced every 2 to 3 years, is kept. The dairy cows of this enterprise feed on cultivated pastures under irrigation.

#### 1.4.4.3 Cultivated pastures

For the greater part, pastures are cultivated on the lands equipped with drag line irrigation. Kikuyu is planted during summer and ryegrass during winter.

Kikuyu seed is planted on one hectare. Once the grass is well established it is cut right down, and the cuttings are ground and spread over an area of 30 ha. It is then pressed into the ground with a roller and watered. This establishment process takes place every

10 years. During May the Kikuyu is cut back or grazed severely, ryegrass is strewn over it and is then trampled in by cattle. After this the area is fertilized and irrigated, which establishes the ryegrass. This establishment process takes place every year.

## 1.5 SUMMARIZED CONCLUSION

Nine RFs were identified for the Winterton irrigation area with the fixed-resource situation as basis. These RFs form a basis for the identification and analysis of the variable resources.

RFs with irrigation lands of 50, 100 and 200 ha were identified. Combined with this, dry-land areas of 50 and 150 ha and natural veld of 300 ha were identified. Four mechanization systems consisting of 19, 31, 36 and 38 implements were identified for the three different irrigation areas in conjunction with the dry-land areas. These four systems have market values of R123 100; R230 400; R380 400 and R384 400 respectively.

Beef cattle as well as dairy cattle enterprises are also included in the typical farms. The beef cattle enterprise consists of 100 cows, while the dairy cattle enterprise consists of 100 cows in milk.

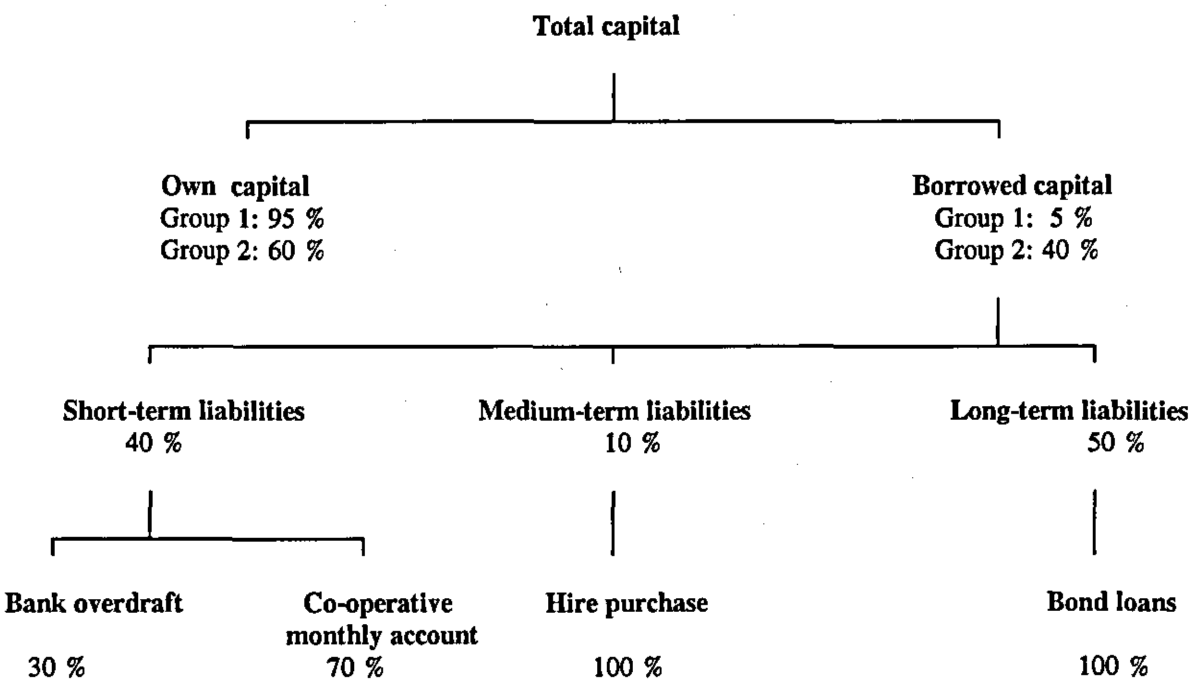


Figure 1.1 Typical capital structure of farmers in the Winterton irrigation area as reflected in balance-sheet information, September 1992

Two types of debt:asset ratios were identified for the region. In the first borrowed capital constitutes 5 % and own capital 95 % and in the second 40 % constitutes capital and 60 % own capital. The typical liability structure for the region can be taken as 40 % short-term liabilities, 10 % medium-term liabilities and 50 % long-term liabilities. The medium-term liabilities comprise only hire purchases and the long-term liabilities bonds. Short-term liabilities comprise 30 % bank overdrafts and 70 % monthly accounts with co-operatives. Figure 1.1 summarizes the typical capital structure of farmers in the Winterton irrigation area.

The cash crops predominantly cultivated in the region are dry-land maize and irrigated maize, soybeans and wheat. Kikuyu and ryegrass are the two most important cultivated pastures, however, further management decisions have to be formulated before any economic analyses can be done.

## 1.6 IMPLICATIONS FOR FURTHER RESEARCH

1) The formulated RFs can be used to do economic analyses at whole farm level as well as on regional level.
2) The differences in capital investments between the 50, 100 and 200 ha irrigation units emphasize the importance of mechanization cost. Analysis at whole farm level therefore necessitates procedures and instruments which will facilitate correct management decisions regarding mechanization.
3) Procedures and instruments which will facilitate management decisions relating to livestock and land are also needed in analyses at whole farm level.
4) The implications of different liability structures on economic profitability and financial viability can be investigated by means of analyses at whole farm level.
5) Economic analyses can be evaluated at whole farm level if the necessary management strategies are formulated.

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# CHAPTER 2

## USE OF THE PUTU IRRIGATION AND IBSNAT CROP MODELS FOR ANALYZING THE ECONOMICS OF CROP PRODUCTION

JHF Botes, DJ Bosch and LK Oosthuizen

### 2.1 INTRODUCTION

Over the past few years agricultural economists have made progress concerning approaches followed and methods used to analyze the economics of crop production (Backeberg and Oosthuizen, 1991). Because of the dynamic and uncertain environment in which production takes place, the importance of the decision maker is explicitly recognized when analyzing the economics of crop production (Backeberg and Oosthuizen, 1991). The goal therefore, is to characterize all the important sources of variability (risk) in a manner which will prove useful and comprehensible to the decision maker (Eidman, 1990). This is typically done by estimating a cumulative distribution function of net returns (CDF-NR). The decision maker is then expected to analyze and select a CDF-NR that best suits his preferences from all the alternatives evaluated (Botes and Oosthuizen, 1991). When yields for alternative production and/or management strategies are estimated, crop models are increasingly used to give due consideration to the dynamic and uncertain environment in which crop production takes place. Different approaches to simulate crop responses are commonly used in crop models. In one method crop responses are simulated using yield response functions (Jones and Ritchie, 1991). Examples are the Hill and Hanks (Hill and Hanks, 1978) and the PUTU irrigation (De Jager and King, 1974) crop models. An alternative method of simulating crop responses is by using a more mechanistic approach to crop growth (Ritchie, 1991). Examples of such models are the IBSNAT (IBSNAT, 1986) and the EPIC models (Williams, Jones and Dyke, 1984). Verification and validation are used to ensure the credibility of the research results. The questions raised by Oreskes, Shrader-Frechette and Belitz (1994); Konikow and Bredehoef (1992) about the philosophical basis of the terms verification and validation do not negate the fact that crop models must be tested and evaluated in terms of their appropriateness for addressing specific research problems.

Validation techniques used to validate crop models have not yet been specifically adjusted to account for the fact that the economics of crop production analyze the CDF-NR for alternative production and/or management strategies. The increased use of crop models for analyzing the economics of crop production requires the development and application of methodologies to assess the validity of these models in terms of their suitability to simulate CDFs for alternative production and/or management strategies accurately. There is also uncertainty as to whether risk attitudes will influence model credibility and selection. The aim of this chapter is, however, not to determine whether the crop-growth models are truly representative of the total natural system they represent, but rather to better evaluate model performance, determine strengths and weaknesses, find where improvements are needed, and determine whether the models appear appropriate for their intended use.

The objectives of this research were the following:

1) To identify critical characteristics affecting the assessment and selection of crop models.
2) To identify a general procedure to guide researchers working with already developed crop models to assess the validity of crop models.
3) To adjust this procedure to specifically account for the fact that the economics of crop production analyze the CDF-NR for alternative production and/or management strategies.
4) To apply this procedure to assess the validity of the IBSNAT crop-growth simulation and the PUTU crop-yield simulation (called PUTU irrigation) models in terms of their suitability to analyze the economics of crop production under diverse production conditions in South Africa.
5) To determine whether the types of errors made by crop models are more important to risk-seeking, risk-neutral or risk-averse decision makers. In other words, will risk preferences influence the selection of crop models used for analyzing the economics of crop production?

## 2.2 CONCEPTUAL MODEL

The validity of simulation models, and therefore also of the information derived from using a simulation model, can be established by answering two questions (Sargent, 1979). The process of answering the first question: "Does the simulation model behave as the model builder (or user) believes?" is called verification. In other words, verification deals with constructing the simulation model correctly (Balci, 1991). According to Gass (1983), model verification consists of two parts. In the first part experimentation is used to *debug* the logic of the computer program. The correctness of the numerical and data procedures as carried out by computer program is demonstrated in the second part.

The second question deals with the adequacy of the simulation model in representing the real-world system, given the objective(s) of developing the model and/or the intended use of the model. The process of answering this question is called validation. Law and Kelton (1990) define validation as the process concerned with determining whether the conceptual simulation model (as opposed to the computer program) is an accurate representation of the system under study.

Two basic approaches can be used to validate simulation models. Inductivism draws conclusions regarding model performance by observing, collecting evidence and detecting patterns of agreement or disagreement between model and real world output (Neelamkavil, 1987). Neelamkavil (1987:68) states that "the inductivist theory assumes that the ultimate reality can be accessed by collecting data". Two apparent problems arise from using this approach. Firstly, the fact that no errors occurred in the past does not guarantee error-free performance in the future. Secondly, the problem of data validity further complicates the use of this approach, *e.g.*, the inability to repeat the same experiment under exactly the same conditions.

Deductive reasoning, the second approach, combines ideas with facts that are accepted as truth. Reasoning moves from the general to the particular. This approach validates simulation models by making an educated guess about the internal structures (processes) of the system that is simulated (formulate an hypothesis). This hypothesis is tested against the simulation model's structure and output data. This process is repeated until the results are satisfactory. Neelamkavil (1987:69) states that "the deductive theory emphasizes the importance of the relative rather than the absolute nature of truth".

According to Neelamkavil (1987), neither of these approaches can guarantee perfect validation. In fact, it is questionable whether numerical models of natural systems can ever be proven to fully representative of the total natural system (Oreskes, Shrader-Frechette and Belitz, 1994; Konikow and Bredehoef, 1992). The best chance of assessing model validity correctly is by using both the inductive and deductive approaches in conjunction with the specific steps in the model development process.

### 2.2.1 Verification and validation

According to Gass (1983) and Sargent (1979; 1988) model verification and validation are related to specific steps in the model development process[1]. Figure 2.1 is a simplified schematic representation of the modelling process. The concept of model verification and validation as well as the relationship between verification and validation will be discussed with reference to Figure 2.1.

The "problem entity" in Figure 2.1 represents the real world biological crop-growth system. The biological crop-growth system is complicated because it consists of different subsystems (*e.g.* plant, soil and weather), each of which is, in turn, dependent on and influenced by other processes (*e.g.* the plant system is influenced by solar radiation, temperature and photoperiod). The extent to which the biological crop-growth system can be simulated largely depends on the possibility of acquiring data that adequately represent all the processes.

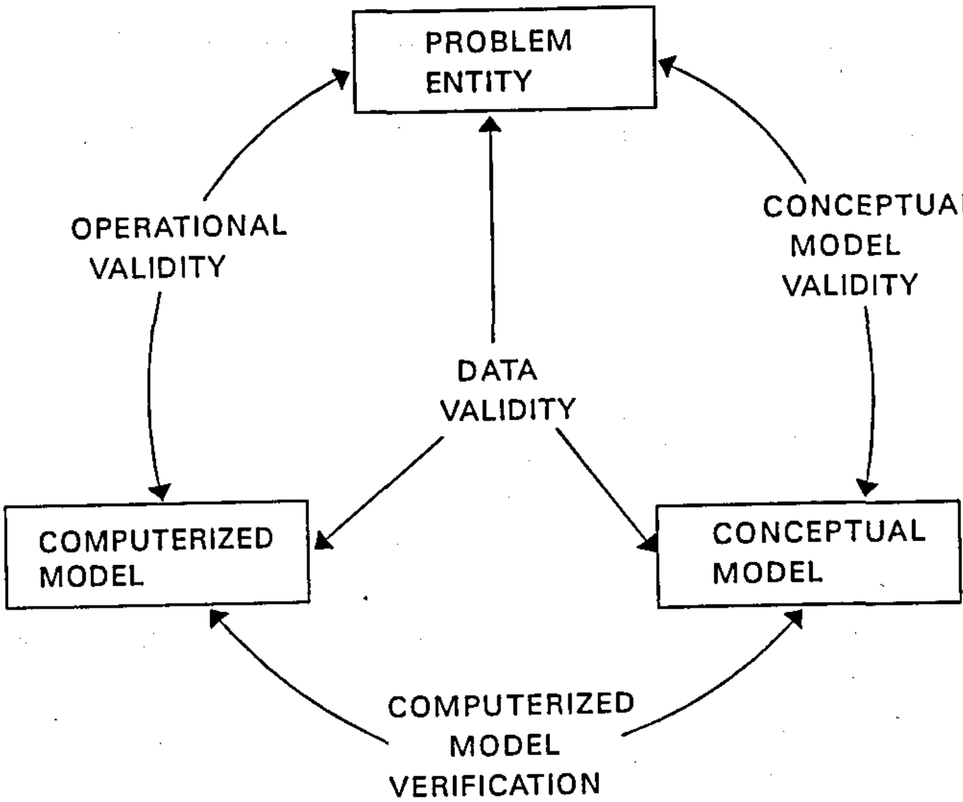


Figure 2.1 Simplified version of modelling process (Sargent, 1979; 1988)

1. The explanation is in part adopted from Sargent (1979; 1988) and Shannon (1981).

The "conceptual model" is the mathematical/logical/verbal representation of how the model builder perceives and understands all the processes and their influences on the real-world system. The conceptual model is developed through analyzing and modelling all aspects of the biological crop-growth system. Law and Kelton (1990) calls the process of determining whether the conceptual model is suitable for the specific research problem the face validity of a simulation model.

The "computerized model" is the conceptual model implemented on a computer, and it is developed through a computer programming and implementation phase. In the implementation phase, experiments on the computerized model are conducted to determine whether the computer model can adequately represent the crop-growth system.

Sargent (1988) identifies four types of validation or verification stages related to specific steps in the model development process.

#### 2.2.1.1 Conceptual model validity

Conceptual model validity is defined as the process of determining whether the theories and assumptions made in the development of the conceptual model are correct, and whether the conceptual representation of the biological crop-growth system is suitable for the intended use of the model. It must, therefore, be determined whether the level of detail[2], logic and structure included in the conceptual model are appropriate for the intended use of the simulation model. Appropriate statistical methods should be used to determine whether fitted distributions are correct, and all theories used in the model should be reviewed to ensure that they have been applied correctly (Sargent, 1988). Determining conceptual model validity usually means examining the flowchart model or the set of model equations. Knowledgeable people can be used to determine whether the computer program and its logic are correct by ascertaining whether the model is reasonable (face validation) and/or by following (tracing) the behaviour of key variables through the model. Traces are the primary validation techniques used in establishing conceptual model validity.

#### 2.2.1.2 Computerized model verification

Secondly Sargent (1988) defines computerized model verification as the process of ensuring that the conceptual model is understood, implemented, and coded correctly by the programmer. In addition, the computer program must be *debugged* and tested for

2. Law and Kelton (1990: 300) provide a few general guidelines for determining the level of detail required by a simulation model.

correctness and accuracy. Law and Kelton (1990), Shannon (1981) and Sargent (1985) suggest that program design and development procedures applied in the field of software engineering should be used in developing and implementing computer programs. These include techniques such as top-down design, structured programming and program modularity.

A much more difficult process is that of *debugging* the programming, and testing it for correctness and accuracy. This process usually firstly involves testing the simulation functions, then each submodel separately and, lastly, the overall model to establish and determine model correctness (Sargent, 1985). Fairley (1976) suggests two basic approaches to test the code of computer models for accuracy and correctness: static and dynamic testing (analysis). The static approach is basically a walk-through procedure where the structural property of the program is examined and tested for accuracy by tracing (following) specific entities through the model. The dynamic approach, on the other hand is used to analyze and test simulation results under different conditions (different input parameters) in order to determine their correctness. Both the static and dynamic approaches are used until the potential user has sufficient confidence in the correctness of the computer model under all anticipated conditions.

#### 2.2.1.3 Operational validity

Thirdly operational validity is defined as the process of determining whether the model's output data are sufficiently accurate for the model's intended use within its prospective field of application (Balci and Sargent, 1984). Operational validity is therefore a process whereby the model builder and/or the user try to assess whether the margin of error between actual and predicted outcomes is significant in the context of the proposed research. This process will establish an acceptable level of confidence in the model. Unfortunately there is no specific decision rule that can establish the validity of a simulation model, because each study and each user present a unique challenge to the simulation model. The concept of validation is therefore, according to Shannon (1975), not a binary decision variable, but rather a question of degree. Neelamkavil (1987:70) describes it as "a philosophical impossibility". An idealistic goal (rule) proposed by Law and Kelton (1990) is to determine whether decisions made about the system, using the simulation model, are similar to those that would be made if it were feasible and cost-effective to experiment with the real system.

Because there is no fixed definition or decision rule for establishing model validity, there is no specific procedure or algorithm for validating simulation models. Sargent (1988) and

Shannon (1981) list a large number of techniques that can be used separately or in combination to validate simulation models. The characteristics of the research problem and simulation model will largely determine which validation technique(s) can be used (Balci and Sargent 1982, Shannon 1981).

#### 2.2.1.4 Data validity

The last part of model verification and validation as identified by Sargent (1988) is data validity. Data validity concerns the collection of appropriate, accurate and sufficient data for validating model performance. The collection of data is very important, because such information is required in order to develop the conceptual model, test and evaluate the simulation model, and perform experiments. It is also costly, difficult and time consuming to obtain sufficient, accurate and appropriate data (Sargent, 1988). The lack of valid data is often the reason why attempts to validate simulation models fail. In fact, the statement made by Oreskes, Shrader-Frechette and Belitz (1994), as well as Konikow and Bredehoef (1992) that "numerical models of natural systems can not be validated" is directly related to the data validity problem. These authors argue that because experimental data can never be fully representative of the total natural system, it is impossible to be 100 per cent sure that the model is 100 per cent valid.

## 2.3 CHARACTERISTICS AFFECTING MODEL VALIDATION

Sargent (1979:499) identifies three critical characteristics affecting the validation of simulation models. These characteristics need to be determined before deciding on a specific validation procedure to assess the validity of the IBSNAT and PUTU irrigation crop models in terms of their suitability for analyzing the economics of crop production under diverse production conditions in South Africa. The first characteristic concerns the problem itself; the second is related to the simulation model, and the third concerns the system under research.

### 2.3.1 Problem characteristics

The characteristics of the problem to which crop models are applied will first of all affect the level of model sophistication required. For example, if the problem under study is the evaluation of alternative management strategies, the concern is prediction of system output and not the biological mechanisms which give rise to these outputs. Consequently, less sophisticated simulation models, such as regression models, can be used. If the problem under investigation is to understand unknown systems better, the principal concern would be *the gathering of information, the formulation of hypotheses and guiding further* research (Brockington, 1979:114). In this case, a more sophisticated model should be used.

Secondly, the characteristics of the problem will affect the outcome variable(s) selected to validate the model. For example, if a model is used to simulate leaf growth, the difference between the actual and simulated leaf area indexes can be used to validate model performances. If the model is used to analyze the profitability of crop production, the difference between the actual and simulated profitability levels should be analyzed.

### 2.3.2 *Simulation model characteristics*

The second characteristic is the simulation model, *e.g.*, what are the assumptions made in the conceptual model in order to represent the real-world system? It is important to be familiar with the characteristics of the simulation model for two reasons. Firstly, the nature of the problem under investigation will determine the characteristics of the simulation model to be selected. Secondly, the characteristic of the simulation model will determine the selection of appropriate model validation technique(s)/statistics.

A model can be characterized as either deterministic or stochastic (Ritchie, 1989). Deterministic models produce a unique outcome for a given set of events. Stochastic models, on the other hand, account for spatial variability by quantifying the degree of uncertainty associated with a given set of events. Balci and Sargent (1982) make a similar distinction, but refer to the two categories as trace- and self-driven models.

Trace-driven (also called retrospective or deterministic) simulation models combine measurement and simulation by using actual data as model input. The model and system output data are, consequently, inter-dependent (Balci and Sargent, 1984). According to Law and Kelton (1990), output processes of almost all real-world systems are non-stationary (characteristics of the system change over time) and auto-correlated. The use of interval statistical measures like correlation coefficients (r), coefficient of determination ($R^2$) and confidence intervals (t and F statistics) to assess model validity, is therefore of limited or no value (Willmott, 1982). Furthermore there is concern about the appropriateness of hypothesis testing as a valid statistical approach in model validation, because the model is only an approximation of the real-world system and can therefore never be the "same" as the real-world system (Law and Kelton, 1990:299).

These problems were overcome by Willmott (1982) who recommends a combination of summary and difference measures to validate deterministic simulation models. The summary measures are: observed mean, predicted mean, standard deviation of the observed values, standard deviation of the predicted values, the intercept (a) and the slope (b) of the least-square regression and regressing the predicted value on the observed values. Summary measures used in conjunction with data display graphics (scatterplots) describe the quality of the simulation, *i.e.*, determine whether the predicted value underestimates or overestimates the corresponding observed values.

The difference measures are: mean absolute error (MAE), root mean square error (RMSE), root mean square error-systematic (RMSEs), root mean square error-unsystematic (RMSEu) and Willmott's "index of agreement" (d-index). Difference measures are all derived from the differences between each set of predicted and observed values ($P_i$- $0_i$), although each measure uses different calculation procedures (mean or root) to describe the magnitude of the differences (see Willmott, 1982 for computational formulas). According to Willmott (1982), MAE and RMSE are among the best overall measures of model performance, because they summarize the mean difference between the predicted and actual values. RMSE is generally more accurate, because it is a higher estimate of the actual average error, especially when there are extreme values present. The RMSEs are calculated to determine how well the model explains the major trends or patterns present in the actual data. High values of RMSEs indicate that there are some systematic differences present in the errors, and that model predictions might be improved by specifying new model parameters. RMSEs are calculated by first squaring and then summing the differences between the least square regression values ($\hat{P}_i$, where $\hat{P}_i = a + bO_i$) and the observed values, and then computing the square root; *e.g.*, RMSEs = $[N^{-1} \Sigma (\hat{P}_i - O_i)^2]^{0.5}$. The systematic difference should thus approach zero. The RMSEu describes the unsystematic part of the error. The RMSEu is calculated similarly, but the differences between the model predictions ($P_i$) and the least square regression ($\hat{P}_i$) values are used instead; *e.g.*, RMSEu = $[N^{-1} \Sigma (P_i - \hat{P}_i)^2]^{0.5}$. In this case the errors are random and cannot be corrected by specifying new model parameters. This problem can be overcome by correcting possible problems (errors) in the actual data and/or collecting additional data for the analysis. According to Willmott (1982), the RMSEu should approach the RMSE. This array of statistics is also used by Otter-Nacke, Godwin and Ritchie (1986). The d-index is a widely used measure which is used to make cross-comparisons between different models. The d-index is dimensionless and is both a relative and bounded measure. Willmott (1982) proved that the d-index is a more accurate relative measure than $R^2$ for comparing different models. The d-index, like $R^2$, can take on values between 0 and 1.

A self-driven (also called distribution driven) simulation model is stochastic in nature, because random numbers are used to generate cumulative distributions or stochastic processes. In this case the model and system output data (response) are independent and identically distributed (IID) (Balci and Sargent, 1984). Consequently the assumptions of interval statistics are not violated. It is thus permissible to use interval statistics to assess model validity, including, for example, Chi-square tests and Kolmogorov-Smirnov tests.

Most crop models are deterministic. Deterministic models can be further categorized into mechanistic and functional models (Ritchie, 1989). According to Jones and Ritchie (1991), mechanistic models are models that incorporate the most fundamental mechanism of each process. Penning de Vries (1977) refers to these types of models as "scientifically interesting" because of the exploratory nature of the research. These models should be assessed in terms of the contribution that they make towards stimulating and directing new research. Assessing a model's contribution to new research is very difficult, because of the difficulty of defining precise performance targets (Brockington, 1979).

Functional models, on the other hand, represent the same processes, but use simplified ways of modelling them (Jones and Ritchie, 1991). As a result, less input data and expertise are required, making functional models the most useful type of model for studying management and production economic issues. Because functional models are developed under specific assumptions for a specific purpose, model assessment should be based on validating system output. Precise performance targets should be set up in accordance with the assumptions made during model development, the purpose for which the model is developed (model objectives) and the intended use of the model (characteristics of the problem).

It is difficult to distinguish between mechanistic and functional models, because all models of plant-soil-weather systems use some level of empiricism in order to reduce input requirements or explain some less understood part of the system (Ritchie, 1989). For example, crop processes such as photosynthesis and partitioning can be treated mechanistically or functionally.

### 2.3.3 System characteristics

The third characteristic concerns the system under investigation; for example, is the biological crop-growth system observable or not, and what type and amount of experimental data are available. The system characteristic is important, because it determines whether the inductive (objective) or the deductive (subjective) approach should be used to establish operational validity (Sargent, 1988). The objective approach is usually used if the system is observable and enough data have been collected or generated by another model for use in formal statistical tests and procedures, such as closeness of fit and confidence intervals. The subjective approach uses graphics to explore model behaviour when the system is observable, and uses other models to establish model validity if the system is not observable.

Measuring specific system outputs is difficult, because crop-growth processes are interdependent and change significantly with small variations in climate, soil, plant and management conditions. Experimental data are usually also limited to a few measurements over a short period of time, rendering the statistical comparisons between actual and simulated values difficult.

## 2.4 A GENERAL VALIDATION PROCEDURE FOR CROP-GROWTH MODELS

The goal of any validation procedure should be, firstly, to determine under which conditions (state of nature) the model would be invalid, rather than trying to validate the model under all possible conditions. Secondly, it should examine how accurately the model represents the system rather than testing for absolute validity.

The first step in assessing model validity is to characterize the problem under research. The second step is to examine the conceptual model, keeping the specific characteristics of the research problem in mind. In its simplest form, step two determines whether the simulation model is deterministic or stochastic. Deductive reasoning is the best approach to use if the simulation model is deterministic, especially in the case of researchers using already developed simulation models. The inductive approach can also be used if data on individual processes are available. In stochastic models this, for example, will entail the refitting of distributions used as model input.

Computerized model verification requires a high level of computer programming knowledge and is therefore highly technical. Consequently, it is questionable whether the research community working with already developed crop models should test and select crop models solely on the basis of the correctness of the computer code. It is also reasonable to assume that verification has already been done prior to distributing the crop-growth simulation model.

The third step is to assess the operational validity of the crop models. Inductivism is the predominant approach, especially if the system under study is observable and experimental data have been collected. However, care must be taken that the data collected for model validation are valid, *i.e.*, that the data are accurately determined and representative in terms of the research problem under investigation.

Due to the deterministic nature of most crop models, the array of statistics described by Willmott (1982) can generally be used to compare the simulated responses to experimental observed responses. The type and character of the simulated and experimental responses used will, however, change as the nature of the research problem changes.

## 2.5 EMPIRICAL MODEL

### 2.5.1 The economics of crop production

Net returns (NR) from a crop-production system constitute a random variable, because of the variability of both crop yields and product prices. The farmer must know the important characteristics of the cumulative distribution function of net returns (CDF-NR) and be able to manage it. He must know, for example, the expected annual NR and the probability of obtaining lower or higher NR. The following equation is used by Bosch and Eidman (1987) to analyze the variability in before-tax net income (BTNI) when different irrigation-information strategies are used to irrigate maize and soybeans on a representative farm in southwest Minnesota:

$$BTNI = (DY + IY)*P + OFI - OC - PC - IC - YC \qquad (1)$$

where the variables represent dry-land yields (DY), irrigation yields (IY), product prices (P), off-farm income (OFI), overhead cost (OC), production cost (PC), irrigation variable cost (IC) and yield variable cost (YC).

Bosch and Eidman (1987) used a crop-growth model to simulate yields and water use for different information-management strategies (information-crop-soil combination) using 11 years' weather data. The effect of variable yields and water use, for each information-management strategy, was transformed into economic terms by calculating the before-tax net income (BTNI) for each simulation year. Equal probabilities are assigned to the array of BTNI values calculated for each information-management strategy. The array of BTNI values are sorted from the largest to the smallest value and converted into cumulative probabilities. The CDF-BTNI obtained by means of one information-management strategy is then compared to CDFs-BTNI obtained by means of other management strategies.

The analysis of crop production decisions under risk requires valid estimates of probability distribution functions of net returns (CDF-NR) for crops under different production and/or management conditions (Oosthuizen, 1991). Consequently, the performance of crop models must be analyzed in terms of their ability to reproduce the actual CDF-NR accurately. CDF-NR are influenced by the variability of both yields and product prices. However, because crop models are only used to simulate the variability of yield, constant prices can be used in the validation procedure.

Two widely used crop models in South Africa are the PUTU and IBSNAT models. The PUTU and IBSNAT crop models are validated to determine their suitability for analyzing the economic efficiency of maize, wheat and soybean production under diverse production conditions in South Africa.

#### 2.5.1.1 *Implications resulting from examining the problem characteristics*

The characteristics of the research problem necessitate that CDF-NR should be generated and analyzed. As a result, the emphasis shifts from the model's ability to predict system output (comparison of the mean predicted and actual yields) accurately to the model's ability to account for variability within the system. In other words, crop models must be able to simulate yield changes due to changes in production and/or management conditions accurately. The validation of crop models is therefore more a question of the model's ability to reproduce the variability of actual CDF, expressed in economic terms, than of the model's ability to reproduce each level of the specific measured output variable.

### 2.5.2 Comparing the IBSNAT and PUTU irrigation conceptual models

Evaluation of the conceptual models is the second step in assessing model validity. The IBSNAT crop model is essentially a crop-growth simulation model, while the PUTU irrigation model is essentially a crop-yield simulation model. The purpose, however, is not to make a detailed comparison of each of the crop models (*e.g.* maize, wheat, soybeans) within the IBSNAT and PUTU irrigation model groupings. Small technical differences between the different crop models within each model grouping consequently were ignored (see Jones and Ritchie, 1991; De Jager, Van Zyl, Kelbe and Singels, 1987, for a detailed discussion of the conceptual model of the soybean model used in IBSNAT and the wheat model used in PUTU irrigation, respectively).

The IBSNAT and PUTU irrigation model groupings use the same level of detail in the weather and soil subsystems, although the way in which this information is used in the models, differs. The weather input requirements for both model groupings are daily maximum and minimum temperatures, precipitation and solar radiation (which is calculated from sunshine hours). The weather subsystem in each model uses the Priestley-Taylor (Priestley and Taylor, 1972) evaporation equation, or modifications of it, to calculate reference evaporation (Eo). The PUTU irrigation model also offers the option to use the Penman-Monteith (Monteith, 1973) evaporation equation if the weather inputs for this equation are available.

Both model groupings have soil subroutines with state variables, including upper and lower limits of soil water content for each of several layers of the soil. Input requirements are obtained from standard soil classification data. A water balance is kept by subtracting, on a daily basis, the amount of water (1) used by the plant, (2) drained out of the profile, (3) lost from the soil surface through evaporation and (4) runoff.

*The most pronounced difference between the two model groupings is the mechanism used* to simulate crop growth. The PUTU irrigation models use a more functional approach to crop growth than the IBSNAT models.

The IBSNAT models separate the growth and development processes in order to determine to what extent differences in water availability alter each process. This is especially important for accurate yield predictions under conditions where water deficit situations may occur, because the vegetative expansion growth process is more sensitive to water stress than other plant growth and development processes (Ritchie, 1991:101).

In the IBSNAT models the total biomass ($B_t$) of a crop is calculated as the product of the average growth rate (g) and the growth duration (d) (Ritchie, 1991).

$$B_t = d * g \qquad (2)$$

The IBSNAT models divide the growth season into different growth stages (for example, eight growth stages are used in the wheat model). The duration of the different growth stages is simulated by using the concept of thermal time, also referred to as growing degree days (see Ritchie, 1991:104 for a detailed discussion on thermal time).

In the IBSNAT models the average growth rate (g) is simulated by calculating the amount of photosynthetically active radiation (PAR) received from the sun and the amount of leaf surface available for the absorption of PAR for photosynthesis (Ritchie, 1991). By assuming that growth rate is directly proportional to the intercepted amount of PAR, the growth in biomass (the amount of carbon fixed) is simulated by using a constant dry matter light use efficiency (DMLUE). The amount of light intercepted by the plant leaves is dependent on the leaf area index (LAI). The IBSNAT models use a non-linear function of thermal time (degree days) to calculate the total leaf area of all the leaves accumulated on the plant since emergence (Ritchie, 1991).

The biomass produced is then partitioned to the various parts of the plant. The IBSNAT models use a combination of the sink size (grain numbers) concept, the growth in biomass duration in the grainfilling growth stage, and the reallocation of biomass from other parts of the plant to grain, to simulate the final crop yield (Ritchie, 1991).

Although the PUTU irrigation model also divides the crop-growth season into different stages (also eight stages for the wheat model), it does not actually calculate the duration of the different stages. The days of the year (DOY) on which the specific crop-growth stages are reached, constitute one of the input requirements for the PUTU irrigation model. The transpiration ratios in the individual growth stages are normalized according to growth stage potential transpiration to represent crop growth. General averages based on scientific and historical observations are collected and used in the PUTU irrigation model to represent the different growth stages. Yield reduction in each of the specified growth stages is then calculated by using a yield response function as presented by Doorenbos and Kassam (1979). According to Kanemasu (1983:416), yield response functions are variety-, site- and year-specific.

The yield response function represented in Equation 3 (De Jager *et al.*, 1987), assumes that the relative yield deficit (1-Y/Ym) is directly proportional to the relative transpiration deficit (1-T/Tm). The yield reductions for each growth stage is then summed to obtain the total reduction in yield.

$$(1 - Y/Ym) = ky\ (1 - T/Tm) \qquad (3)$$

The ky values (yield response factors) represent the yield reaction to moisture stress. By changing the ky values in the different plant-growth stages, the sensitivity of the plant to moisture stress can be represented.

Maximum evapotranspiration (ETm) is calculated by multiplying reference evaporation (Eo), obtained from the Priestley-Taylor or Penman-Monteith equations, with a crop coefficient (see Equation 4)

$$ETm = kc * Eo \qquad (4)$$

The *crop coefficient (kc) is critical and is expressed in terms of three evaporation* coefficients which correspond to the soil surface wetness (Fg), the leaf area index (Fv) and the hydraulic conductance of the whole crop (Fh) (De Jager, Botha and Van Vuuren, 1981). However, in the PUTU irrigation model, Fv is empirically determined and read into the PUTU irrigation program as model input. Fh is a function of atmospheric evaporative demand and soil water content. It is computed using an interactive technique.

#### 2.5.2.1 General conclusions from conceptual model validation

Both the simulation models can be classified as basically functional in nature. However, the degree of functionality differs. For example, the crop-response system in the PUTU irrigation model is more functional than the crop-response system in the IBSNAT models, because the growth rate and growth duration are not simulated, but obtained as model input. PUTU irrigation also uses a yield response function which is a simplification of the plant-growth system.

Using deductive reasoning, it is clear that the PUTU irrigation models are of little value when studying management decisions related to the timing of pesticide application, scheduling the orderly harvesting of crops and synchronizing the flowering of cross-pollination for hybrid seed production. Growth duration and development problems might also be experienced, especially if the PUTU irrigation models are not calibrated for the specific production conditions.

### 2.5.3 Data validity

Experimental data for maize, wheat and soybeans were obtained from researchers throughout South Africa (see Table A2, Appendix A). Seven data sets for maize were obtained from Potchefstroom, Ottosdal, Sandvet, Glen, Rooipoort, the PK le Roux Dam[3] and Cedara. The Potchefstroom and Ottosdal data were supplied by Andre du Toit (Du Toit, 1991) of the Grain Crops Institute. The Potchefstroom maize data were collected on

3. Known as Vanderkloof Dam since 29-11-1994.

a well-drained Hutton Shorrocks soil for three cultivars, PNR473, A1894W and PNR6363, planted at weekly intervals from September 7, 1990 to January 25, 1991. Consequently, this data set consists of 63 treatments. PNR473 was planted at Ottosdal under dry-land conditions on December 18 using six row widths.

The Sandvet, Glen and Rooipoort data were supplied by Malcolm Hensley and Herbert Hattingh of the Glen Agricultural Development Institute. The Rooipoort data were collected west of Potchefstroom on a Hutton Clansthall soil, planted with PNR473. Three row widths were planted on December 7 at Sandvet using PNR6528. This experiment was repeated at Glen the following year, but this time PNR473 was used and planting took place on January 3.

The PK le Roux Dam data were obtained from a published report for the Water Research Commission (Bennie, Coetzee, Van Antwerpen, Van Rensburg and Burger, 1988). This data set consists of five treatments where soil water was measured on a weekly basis. The yields were also measured.

The last maize data set was obtained from John Mallett of Cedara Agricultural Development Institute (Fleischer, Mallett, Clemence and Blakeway, 1991). This set consists of three data sets each collected for RS5206, PNR6363 and PNR6463 on planting dates: October 23, November 13 and December 3, 1990.

A total of 90 yield observations for maize were thus collected from all over South Africa. From the 90 yield observations, 68 received irrigation, 13 were grown under dry-land conditions where the annual rainfall is below 650 mm/year, and nine observations were also collected under dry-land conditions, but where the annual rainfall is considerably higher (about 900 mm/year). Soil water content was only measured on 20 treatments throughout the growing season.

Wheat data were obtained for the PK le Roux Dam area, Glen, Roodeplaat and Preston Park in the Eastern Cape. The PK le Roux Dam data consist of seven treatments and were also obtained from the Bennie Report (Bennie *et al.*, 1988). Herbert Hattingh again supplied wheat data from Glen. This data set consists of three treatments of Scheepers 69 planted in rows of 45, 60 and 75 mm, respectively. The wheat was grown under dry-land conditions where both yields and the soil water contents were measured. The Roodeplaat data were obtained from a paper delivered by Van Rensburg, Bennie and Walker (1991). Wheat cultivar SST66 was planted on a Shorrocks soil and irrigated at six different irrigation levels ranging from full irrigation to nearly dry-land conditions. Both yield and soil water were measured. The last set of data was collected by Rex Marr of the Dohné Research Station. This set consists of yield data collected under very dry conditions in the Eastern Cape on different soils during the period 1982-1990. No soil water measurements were made.

All the soybean data were received from Michiel Smit of the Grain Crops Institute, Potchefstroom. Data received for Potchefstroom and Cedara were yield measurements for 1981-1990 of the cultivar Forrest on a Hutton soil. Yield data received from Bethlehem were from four different planting dates during 1980. Unfortunately no data where the soil water content was measured could be found.

A total of 29 yield observations for wheat and 20 yield observations for soybeans were collected from all over South Africa. Thirteen of the 29 wheat treatments had received irrigation while the remaining 16 had been produced under dry-land conditions. All the soybean data collected were cultivated under dry-land conditions.

In total, 139 yield data points were obtained for all three crops, while 36 treatments were obtained where the soil water content was continuously measured throughout the growing season. There were probably some errors involved in making these measurements, due to experimental procedures and lack of expertise of those taking the measurements. However, the accuracy should prove more than adequate for assessing the validity of the IBSNAT and PUTU irrigation models in terms of their ability to predict the CDF-NR for maize, wheat and soybeans over space and time, and under conditions of adequate and limited water supply.

A frequent problem with data obtained for modelling is uncertainty regarding the accuracy of the solar radiation estimates, because data on sunshine hours, along with those regarding the other weather variables used to compute solar radiation, are not always from a weather station in close proximity to the experimental site. Other problems are the accuracy of the extractable soil water, initial soil water and the nitrogen status of the soil. All possible precautions were taken to ensure that the most accurate data were obtained and used.

### 2.5.4 Operational model validity

Input files for all 139 experimental treatments were drawn up for both the IBSNAT and PUTU irrigation models. In cases where the initial soil water contents were not given, the initial soil water was adjusted until the simulated soil water content corresponded with soil water measurement made later in the season.

Genetic coefficients, which describe specific cultivar characteristics like the photoperiod sensitivity coefficient, maximum kernel number per plant and the potential kernel growth rate, used in the IBSNAT models to simulate PNR473, A1894W and PNR6363, were obtained from the Grain Crops Institute, Potchefstroom. These coefficients were actually measured in the field while the maize crops were growing. For other maize cultivars the coefficients published by Cedara Agricultural Development Institute (Fleischer *et al.*, 1991) were used. Genetic coefficients used in the wheat model of IBSNAT were obtained from John Purchase at the Small Grain Centre in Bethlehem. No South African genetic coefficients for soybeans could be found. Consequently, the USA coefficients, as published by IBSNAT (1986), were used.

The PUTU irrigation models for maize, wheat and soybeans were calibrated by Den Braanker (1992) with the data set provided by Bennie *et al.* (1988). The calibrated yield response factors (ky), the crop coefficient (kc) and the duration of the growth stages as reported by Den Braanker (1992:37) were used to simulate yield responses for the different crops, management strategies and weather conditions. Maximum yield (Ym) values used in the yield response function to calculate actual yield (Ya) values for maize, wheat and soybeans were 10, 7 and 3 tons per hectare, respectively. These maximum potential yield values were not changed to accommodate differences in planting dates, growth duration, yield potentials or other genetic characteristics. The reasons are twofold. Firstly, much of this information is difficult to obtain, and must be "guessed". Secondly the main reason for using functional models is that there are fewer input requirements, providing maximum yield information by crop variety, soil and climatic conditions would have practically negated this advantage.

The correctness and acceptability of the crop-growth models' input and output were ensured by having a close working relationship with modelling experts, working with both the IBSNAT and the PUTU irrigation models. Prof Jimmy de Jager and his team supervised the simulations done with the PUTU irrigation program, while the research team of Cedara Agricultural Development Institute under supervision of John Mallett checked all the simulation runs done with the IBSNAT model.

The actual and simulated NR for maize, wheat and soybeans at the different localities and under different production conditions were calculated as follows:

$$NR_{ij} = (YLD_{ij} * P_i) - PC_{ij} - SC_{ij} - IC_{ij} - YC_{ij} \qquad (5)$$

Where:

| | | |
|---|---|---|
| $NR_{ij}$ | = | net Returns for crop i at location j; |
| $YLD_{ij}$ | = | crop yield for crop i at location j; |
| $P_i$ | = | product price for crop i; |
| $PC_{ij}$ | = | production cost for crop i at location j; |
| $IC_{ij}$ | = | irrigation variable cost for crop i at location j; |
| $SC_{ij}$ | = | seed variable cost for crop i at location j, and |
| $YC_{ij}$ | = | yield variable cost for crop i at location j. |

Maize, wheat and soybeans yields were multiplied by R418, R681 and R820 respectively. Production cost (PC) for each of the crops at the different localities was obtained from Combud Enterprise Budgets (Department of Agriculture and Water Supply, 1993). The PC estimates used in the analyses of crop production at the different localities are listed in Table A2 (Appendix A). PC values relate to different inputs used at the different locations. Fertilizer cost and the cost of other production inputs remained fairly constant between replication at one specific site. Seed variable cost (SC) was, however, calculated separately because much of the experimental data obtained used different plant populations between experiments at a given location. Irrigation variable cost (IC) was calculated if irrigation water was applied and/or the soil water was measured. If soil water was measured, the difference between the initial soil water and the soil water content at the end of the growth season was calculated and added to the amount of irrigation water applied. A cost of 83 c/mm water applied was used to calculate irrigation variable cost. Yield variable cost (YC) was calculated for using the actual and simulated yields. YC consists of two components, transportation and harvesting cost. Harvesting cost was taken to be R55 per hectare. Transportation was taken to be 56 c/ton/km over an average distance of 30 km. The actual and simulated yields, the actual and simulated soil-water levels and the actual and simulated NR of maize, wheat and soybeans, at each of the treatments, are presented in Table A2 (Appendix A).

Equal probabilities were assigned to the simulated and measured NR for maize, wheat and soybeans. The main concern was the accuracy with which the simulation models can reproduce the CDF-NR for maize, wheat and soybeans, given the diverse production and environmental conditions. After assigning probabilities, the actual and simulated maize, wheat and soybean NR were sorted. Johann Booysen of the Department of Plant Science, University of Potchefstroom, developed a computer program based on the procedures described by Willmott (1982). This program was used to calculate all the summary and difference measures using the simulated NR. Cumulative distribution functions were also represented graphically, because of their usefulness in studying the pattern of differences between the actual and predicted values. A generalized stochastic dominance (GSD) program developed by Cochran and Raskin (1988) was used to determine whether the type of errors made by the simulation models are more important to risk seekers, risk neutrals or risk averters. Absolute risk-aversion coefficients (RAC) between -0,0003 and -0,000017 were used to represent risk-seeking preferences. RAC used for risk neutrals and risk averters varied between, respectively, 0 to 0,00003 and 0,0003 to 0,0017.

## 2.6 RESULTS

### 2.6.1 Validity of IBSNAT and PUTU irrigation models for analyzing the *economics of crop production*

The quantitative measures used to assess the validity of the IBSNAT and PUTU irrigation models in terms of their ability to accurately estimate the actual CDF-NR for maize, wheat and soybeans, are presented in Table 2.1. In addition to the quantitative measures, the CDF for maize, wheat and soybeans are presented graphically in Figures A1 to A3, respectively (Appendix A).

The quantitative measures calculated for maize (Table 2.1) and the graphically presented maize CDF-NR (Figure A1, Appendix A) indicate that both the PUTU irrigation and the IBSNAT crop-growth simulation model were fairly accurate in reproducing the actual maize CDF-NR.

The quantitative measures (Table 2.1) are important for determining the ability of simulation models to account for the variances observed in the actual data. From Table 2.1 it can be seen that the PUTU irrigation model on average underestimated the maize NR by 28 % (R252/ha), while the IBSNAT overestimated maize NR by 2 % (R19/ha). The average noise or unbiased difference, as calculated by the standard deviation (STDEV), was R870/ha for the actual maize NR. The PUTU irrigation and IBSNAT models overestimated the variability by R22/ha and R156/ha, respectively. The usefulness and accuracy of the STDEV statistics, along with $R^2$, however, are questionable when used with deterministic models (Willmott, 1982).

Difference measures are more representative and accurate in their summary of the noise levels. The mean absolute error (MAE) indicated that the PUTU irrigation model, on average, underestimated the actual maize CDF-NR by R270/ha, while the IBSNAT model, on average overestimated maize CDF-NR by R164/ha. The root mean square error (RMSE), another estimate of the model error, suggested that the IBSNAT model was, on an average R122/ha closer to the actual maize CDF-NR than the PUTU irrigation model. Forty-eight percent of the total error (systematic plus unsystematic) as simulated by PUTU, was unsystematic in nature, while the other 52 % was systematic in nature. Fifty-five percent of the total error for the IBSNAT model was unsystematic with 45 % systematic. The relatively large systematic error for both models indicates that there is still room for improving model performance by specifying new (more appropriate) model parameters. The unsystematic component of the error can only be addressed by correcting possible errors in the actual data, collecting additional data and/or changing the way the program simulated changing key processes in the model itself.

Table 2.1 Quantitative measures used to assess the validity of the PUTU irrigation and IBSNAT models in terms of their ability to predict the actual cumulative distribution of net returns (CDF-NR) for maize, wheat and soybeans under diverse production and management conditions in South Africa, 1993

| MODEL | MEAN(1) | STDEV(2) | MAE(3) | RMSE(4) | RMSEs(5) | RMSEu(6) | D-INDEX(7) | $R^2$ (8) |
|---|---|---|---|---|---|---|---|---|
| MAIZE PRODUCTION RISK | | | | | | | | |
| ACTUAL | 885 | 870 | - | - | - | - | - | - |
| PUTU | 633 | 892 | 270 | 344 | 252 | 234 | 0,96 | 0,93 |
| IBSNAT | 904 | 1026 | 164 | 222 | 141 | 172 | 0,99 | 0,97 |
| WHEAT PRODUCTION RISK | | | | | | | | |
| ACTUAL | 769 | 921 | - | - | - | - | - | - |
| PUTU | 1226 | 620 | 490 | 604 | 566 | 213 | 0,86 | 0,88 |
| IBSNAT | 313 | 750 | 456 | 513 | 491 | 149 | 0,91 | 0,96 |
| SOYBEAN PRODUCTION RISK | | | | | | | | |
| ACTUAL | 960 | 516 | - | - | - | - | - | - |
| PUTU | 770 | 393 | 197 | 240 | 228 | 73 | 0,93 | 0,96 |
| IBSNAT | 302 | 653 | 658 | 694 | 666 | 198 | 0,72 | 0,90 |

1. MEAN = Mean Btni, units in R/ha
2. STDEV = Standard deviation, units in R/ha
3. MAE = Mean absolute error, units in R/ha
4. RMSE = Root mean square error, units in R/ha
5. RMSES = Root mean square error - systematic, units in R/ha
6. RMSEU = Root mean square error - unsystematic, units in R/ha
7. D-INDEX = Willmott's "Index of Agreement"
8. $R^2$ = Coefficient of determination

*Along with all the quantitative measures, the d-index suggests that the* IBSNAT *model was* about 3 % more accurate than the PUTU irrigation model. Both the index of agreement (d-index) and the coefficient of determination ($R^2$) are very high (upper nineties) indicating both models' ability to explain most of the major trends or patterns presented in the actual maize CDF-NR. The ability of the PUTU irrigation and IBSNAT crop models to accurately reproduce the actual maize CDF-NR, can also be seen from Figure A2 (Appendix A). The actual maize CDF-NR predicts losses (negative NR) about 20 % of the time, while the NR in excess of R2 000/ha can only be expected less than 10 % of the time. *Both the PUTU irrigation and IBSNAT crop models were able to predict losses and* returns in excess of R2 000/ha with very similar probabilities (20 % of the time losses and 10 % of the time).

The IBSNAT and PUTU irrigation models for wheat, by comparison, were less accurate. The index of agreement was 0,91 and 0,86 respectively, and the $R^2$ 0,98 and 0,88 respectively. On average, the PUTU irrigation model overestimated wheat NR by R457/ha (59 %), while the IBSNAT model, in turn, underestimated NR by an average of R456/ha (59 %). *In addition, both models underestimated the variability in NR by 19* and 33 %, respectively. This trend is clearly observable in Figure A2 (Appendix A). In addition it can be seen that the IBSNAT model was more accurate in simulating the lower end of the wheat CDF-NR (below 50 %), while the PUTU model, in turn, was more accurate in simulating the upper end of the wheat CDF-NR (above 70 %).

The MAEs for the PUTU and IBSNAT models were also relatively large (64 and 59 % respectively) in relation to the mean actual wheat CDF-NR (769). The calculated RMSE indicates that wheat NRs were overestimated by R604/ha and underestimated by R513/ha respectively by the PUTU and IBSNAT models. Consequently, the IBSNAT model was R91/ha closer to the actual wheat NR than the PUTU irrigation model.

Both the PUTU irrigation and IBSNAT crop models for wheat have the potential to improve model performance by specifying new model parameters, because the systematic error for both simulation models was relatively large (73 and 77 % respectively).

The IBSNAT model's prediction of the soybean CDF-NR was disappointing. The IBSNAT model underestimated the mean actual soybean NR by 69 %. By comparison, the PUTU irrigation model underestimated the mean actual soybean NR by 20 %. The same conclusions can be drawn by studying the graphical representation of the soybean CDF-NR in Figure A3 (Appendix A). For example, the IBSNAT model predicted a 40 % chance of obtaining a negative NR from soybean production. In fact, the actual data indicated a 5 % chance to realize a negative NR from soybean production. The PUTU irrigation model was fairly accurate in reproducing the lower end of the soybean CDF-NR, but was less accurate regarding the upper end of the soybean CDF-NR.

The RMSEs was substantially higher for the IBSNAT model (R666/ha) than for the PUTU irrigation model (R228/ha), indicating the need to adjust the American coefficients to render them more applicable to South African soybean cultivars, soils and weather conditions. From the inaccurate soybean NR predictions made by the IBSNAT model, it is also clear that it is very sensitive to the correct specification of model parameters. In the absence of accurate model parameters it is preferable to use more functional simulation models.

Both the IBSNAT and PUTU irrigation models were suitable for analyzing the economics of crop production, with the exception of the IBSNAT model for soybeans. The crop-growth model was fairly accurate in reproducing the CDF-NR, especially considering the diverse production and management data used; as well as the fact that the models were not calibrated for any specific location or management conditions. In practice, however, crop models are used under very specific conditions. For example, when studying the economics of different planting dates, the area, soil and management conditions are held fairly constant with changes in planting dates. This allows the researcher to calibrate crop models to be more accurate under these specific production and management conditions.

Although both the PUTU irrigation and IBSNAT maize models were fairly evenly matched in their estimation of the maize and wheat CDF-NR, the IBSNAT model in both cases proved more accurate based on the d-index and other statistical measures used. However, the increased accuracy of the NR predictions, given the fact that the IBSNAT maize and wheat models are well adapted to South African conditions, must be weighed against the fact that the PUTU irrigation models are more easily adapted to specific farm level production conditions (different crops).

### 2.6.2 The importance of simulation model errors to risk-seeking, risk-neutral and risk-averse decision makers

The amounts (R/ha) that each value in the simulated CDF-NR for maize, wheat and soybean must be lowered (or increased) in order to no longer dominate (or be dominated by) the actual CDF-NR, given risk-seeking, risk-neutral or risk-averse preferences[4], are presented in Table 2.2.

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4. The discussion of stochastic dominance will be presented in Chapter 4.

The amount (R/ha) needed to adjust the PUTU or IBSNAT simulated CDF-NR so that there is no difference between the simulated and actual CDF-NR, varies substantially if risk attitudes change. In other words, the importance of the simulation error between the actual and simulated CDF-NR varies substantially, depending on the risk attitude of the decision maker. For example, the amount needed to be added to each wheat NR value, simulated by the IBSNAT model, is R448/ha if preferences are risk seeking. Only R314/ha is needed if risk preferences are risk averse. In the case of the maize CDF-NR, R21/ha must be deducted from each value in the CDF if risk preferences are risk seeking. If risk preferences are risk averse, however, R29/ha must be added to each value in the distribution.

Table 2.2 The amount by which the maize, wheat and soybean CDF-NR simulated by the PUTU irrigation and IBSNAT models must be lowered(1) (or increased(2)), in order to no longer dominate (or be dominated by) the actual CDF-NR for risk-seeking, risk-neutral and risk-averse decision makers, respectively

| | PUTU | | | IBSNAT | | |
|---|---|---|---|---|---|---|
| | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING(3) (R/ha) | NEUTRAL(4) (R/ha) | AVERSE(5) (R/ha) | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) |
| Maize | +240 | +252 | +250 | -21 | -14 | +29 |
| Wheat | -380 | -448 | -507 | +448 | +441 | +314 |
| Soybean | +191 | +188 | +106 | +635 | +658 | +677 |

1. Amounts that must be lowered are indicated by negative signs (-).
2. Amounts that must be increased are indicated by positive signs (+).
3. Risk-seeking = Absolute risk-aversion coefficients between -0,0003 and -0,000017.
4. Risk-neutral = Absolute risk-aversion coefficients between 0,0 and 0,00003.
5. Risk-averse = Absolute risk-aversion coefficients between 0,0003 and 0,0017.

Selection of PUTU or IBSNAT will influence the result of the computed stochastic efficiency. This occurs to a different degree depending on the risk preference employed. A valid crop-growth simulation model for a specific group of farmers is the model of which the predictions do not greatly differ from the actual predictions for the outcomes of greatest concern to the decision maker in a specific class of risk preferences (risk seeking, neutral or averse).

The selection of a valid wheat model is used as an example. If risk-seeking preferences are assumed, the PUTU model will be selected, because the simulation error is only R380/ha compared to the simulation error of R448/ha for the IBSNAT model. If however, risk-averse preferences are assumed, the IBSNAT model will be selected, because the IBSNAT model produces a smaller error for this group of decision makers than the PUTU model (+R314/ha to -R507/ha). The IBSNAT soybean model proved unable to accurately simulate the actual CDF-NR. The simulation error for all three types of decision makers was more that R600/ha.

## 2.7 CONCLUSION

The critical characteristics affecting the assessment and selection of simulation models are, firstly, the nature of the research problem itself. What are the important variables affecting possible answers to the research problem? The second critical characteristic concerns the simulation model itself. What are the assumptions and the techniques used in the simulation model to represent the real-world system? Lastly, the characteristics of the system under study are also very important. What are the nature, accuracy and quantity of experimental data available?

The procedure used to assess the validity of crop models should include both the inductive and deductive approaches in conjunction with the specific steps in the model development process.

The validation procedure was adjusted to evaluate the importance and magnitude of differences between the actual and simulated CDF-NR, instead of analyzing the differences in yield predictions alone.

The maize models of both IBSNAT and PUTU irrigation proved suitable for analyzing the economics of crop production under diverse production conditions in South Africa. Both the wheat model and the soybean model of PUTU irrigation show promise, but need further work to improve accuracy. The soybean model of IBSNAT proved disappointing and at present is not valid for use under South African production conditions if no locally determined genetic coefficients are available.

The amount with which each value in the simulated CDF-NR should be adjusted in order to no longer dominate (or be dominated) by the actual CDF-NR, varies substantially if risk attitudes change, but does not seem to follow a predictable pattern, *e.g.*, it is always higher for risk averters than for risk seekers.

It was found that the importance of the simulation error differs substantially depending on the risk attitude of the decision maker. In other words, risk preferences can influence the selection of crop models.

## 2.8 IMPLICATIONS FOR FURTHER RESEARCH

Experimental data requirements are the most limiting factor affecting the validation of crop models. This is especially apparent when specific processes, such as the movement of water through the soil and roots, have to be validated. Yield and soil water data, measured under conditions of limited water supply, are also very limited. In addition, no economic data have been collected. This includes data on aspects such as the costs of pesticides, fertilizer and other production inputs.

Another important area for further research is the genetic coefficients used in growth models. The inaccuracy of the IBSNAT soybean simulation model was largely due to the absence of South African determined crop-genetic coefficients.

When validating and/or verifying numerical models of natural systems (like crop models) one should always remember that models are only representations of real-world systems. Simulation models can therefore only evaluate in relative terms and their productive value is always open to question (Oreskes *et al.*, 1994).

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# CHAPTER 3

# A SIMULATION OPTIMIZING APPROACH FOR EVALUATING INFORMATION FOR CROPS UNDER LIMITED WATER SUPPLY

JHF Botes, DJ Bosch and LK Oosthuizen

## 3.1 INTRODUCTION

Many farm problems are dynamic in nature resulting in a shift away from the static neoclassical models towards more dynamic analyses (Kazmierczak and Norton, 1990:1). Crop-growth simulation models have become useful tools among agricultural economists studying the economic efficiency of irrigation, because such models are able to account for interaction among atmospheric, soil, plant and management variables (Bosch, Eidman and Oosthuizen, 1987).

Although crop models can reproduce the dynamic irrigation environment, they must be combined with a method that systematically evaluates alternative irrigation scheduling rules under uncertain conditions in order to find the optimum strategy, given the irrigation information used and the goal of the irrigator (Bosch *et al.*, 1987). This is difficult, especially if irrigation water is limited, because most optimizing algorithms require that the system objective function and constraints must be expressed analytically (Kazmierczak and Norton, 1990:1). Secondly, it is difficult to find the optimum irrigation rule under deficit irrigation conditions by doing multiple simulation runs and then selecting the irrigation rule which maximizes the net returns for a given information level without an efficient search procedure (Kazmierczak and Norton, 1990:1). Kazmierczak (1991) demonstrates that a simulation optimizing approach can be used successfully to optimize different pest regulatory actions for a US apple production system. This technique has however not yet been used to optimize different irrigation-scheduling strategies under dynamic plant-growth conditions.

The main objective of this chapter was to develop a simulation optimizing approach for the optimization of management decisions under dynamic plant-growth conditions. The feasibility of combining a crop-growth simulation model, an economic model and an efficient search optimizer to produce a model capable of yielding realistic estimates of the value of irrigation information under conditions of limited water was demonstrated. This simulation optimizing approach will allow researchers to determine the value of irrigation information under limited water supply conditions.

The specific objectives were the following:

1) To evaluate the effects and determine the value of irrigation-scheduling information under conditions of unlimited and limited water supply for a risk-neutral decision maker.
2) To determine to what extent plant extractable soil water (PESW) and available water supply influence the value of information.
3) To determine the effect of yield and output price correlations on the increase in expected net returns generated by using perfect soil-water information on two soil types under conditions of limited and unlimited water supply.

## 3.2 CONCEPTUAL MODEL

### 3.2.1 The complex method

Two main difficulties are involved in the search for an optimum for an irrigation scheduling problem. Firstly, the research problem is unsuitable for classical non-linear or boundary-value techniques, because the simulation response functions cannot be expressed analytically in terms of the decision rule (Kazmierczak, 1991). Secondly, the search methods cannot be based on system responses of two or more points in the previous simulation step, because the response of a simulation model is often a stochastic function. Consequently, the comparison of responses based on one observation at each point may result in the selection of a wrong point or a wrong direction for the next step (Azadivar and Lee, 1988:332).

Exhaustible resource problems usually have many near-optimal solutions, especially if the response surface is fairly "flat" in the region of the optimum. Chapman (1987) found that different depletion paths yield multiple near-optimal solutions when applied to studying the allocation of crude oil. Rowse (1988:649) showed that there are many other near-optimal solutions to Chapman's oil allocation problem.

Kazmierczak (1991) introduced a hybrid approach that can optimize such complex dynamic systems. The approach employs computer simulation and theoretical conditions derived from the maximum principle to optimize non-analytic deterministic or stochastic systems. The complex search method which Kazmierczak (1991) used was neither based on gradient (first-order derivatives) nor on quadratic forms (second-order derivatives), but used a geometric figure to move along the response surface in search of a maximum (Nelder and Mead, 1965:311). The complex method approaches the maximum by moving away from the low values of the objective function rather than by trying to move in a line towards the maximum (Olsson and Nelson, 1975:46).

The complex method, also known as the constrained simplex (Box, 1965:43) or Nelder-Mead simplex algorithm (Nelder and Mead, 1965), makes the following assumptions:

1) The theoretical function Y(X) is a real-valued (but unknown) function.
2) There exists a finite constant M such that the variance of [Z(X)] $<$ M for all X.

The problem under research, in its general form, can therefore be formulated as follows (Azadivar and Lee, 1988):

$$\text{MAX}^{(1)} \quad E[Z(X)] = Y(X) \qquad (1)$$

$$\text{subject to } g_j(X) \begin{matrix} \leq \\ = \\ \geq \end{matrix} c_j, \; j = 1,2,\ldots\ldots,m,$$

where X is a vector consisting of discrete-value decision variables $x_1,x_2,\ldots,x_n$, Z(X) is the random variable corresponding to the output of the simulated system, Y(X) is the regression function of Z(X) and $g_j(X)$ is a set of m constraints on X.

The formulation of the problem begins with identification of the decision variables $(x_1,x_2,\ldots,x_n)$ for which the expected value of the response, E(X) is optimized. An initial simple consisting of a number of vertices, $X_1,X_2,\ldots,X_k$, is then constructed. The number of vertices (k) in the initial simplex is usually $k = 2n + 1$, but $k = n + 1$ can also be used for a large number of decision variables (Azadivar and Lee, 1988). The initial values of the decision variables, and therefore the selection of the vertices $(X_1,X_2,\ldots,X_k)$, can either be generated randomly or be spread uniformly throughout the solution space.

The initial simplex is next ordered in accordance with the stated objective function. Ordering is conducted by evaluating the objective function (simulation response) for each vertex in the initial simplex. The responses and the vertices are then ranked from the highest to the lowest value. The vertex, $X_w$, resulting in the lowest value of the response function, assuming the function is to be maximized, is identified.

1. See Azadivar and Lee (1988:332-334) for proof.

The algorithm proceeds by moving the simplex away from the worst vertex, $X_w$. This is done by attempting to replace $X_w$ with a superior vertex. Four basic operations[2], namely reflection, expansion, contraction and shrinkage are used to conform the simplex to the characteristics of the response surface (Olsson and Nelson, 1975:46).

The movement of the simplex begins by calculating the hyperspace centre of non-worst vertices which serves as a focal point through which a potential superior vertex can be found (Kazmierczak, 1991:196). This hyperspace centre is called the centroid, ñ, and is calculated as follows:

$$\tilde{n} = {}^{1}/_{k} \sum_{i=0}^{k-1} v_i \tag{2}$$

The simplex is then moved in the direction of the centroid by calculating a reflected vertex, $X_r$ (new vertex). A reflected vertex is calculated as

$$X_r = (1 + \alpha)\tilde{n} - \alpha X_w \tag{3}$$

where $\alpha$ is a positive constant that determines how far along the inferior vertex the new vertex will be located.

The response from the reflected vertex is compared to the next-to-worst ($X_w$-1) and the best vertex ($X_b$) in the initial simplex. The basic operation, and thus the movement of the simplex, depends on whether the simulation response for $X_r$ is (1) superior to $X_w$-1, but inferior to $X_b$, (2) superior to $X_b$, or (3) inferior to $X_w$-1.

If, in the first situation, the simulation response of $X_r$ is superior to the $X_w$-1, but inferior to $X_b$, then $X_r$ replaces the $X_w$ as a member of the simplex. Stopping criteria are then tested, and if not satisfied, the vertices are reranked and the process begins again.

Secondly, if $X_r$ produces a simulation response that is superior to $X_b$, *i.e.* the reflection produces a new maximum, then the search continues in the direction of the original reflection. This is accomplished by calculating an expanded vertex ($X_e$). The expanded vertex is calculated as follows:

$$X_e = \sigma X_r + (1 - \sigma)\tilde{n} \tag{4}$$

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2. The calculation procedures are adapted from Kazmierczak (1991:196-198). Also see Nelder and Mead (1965:308-309).

where expansion coefficient, $\sigma$, is a positive constant.

The expanded vertex, $X_e$, replaces $X_w$ as a member of the simplex if the simulation response for $X_e$ is superior to $X_r$. If, however, $X_e$ is not superior to $X_r$, then $X_r$ replaces $X_w$ and a new $X_r$ is calculated after reordering (Kazmierczak, 1991).

Thirdly, if $X_r$ produces a simulation response that is inferior to the $X_w$-1, a contracted vertex, $X_c$, is calculated to move the reflected vertex back along the projection path towards $X_w$ (Kazmierczak, 1991:197). The contracted vertex is calculated as

$$X_c = \beta X_t (1 - \beta)\tilde{n} \qquad (5)$$

where $0 < \beta < 1$ is the contraction coefficient, and $X_t$ is the better vertex of $X_w$ and $X_r$, in terms of their system response.

The worst vertex, $X_w$, is replaced by $X_c$ to form a new vertex if $X_c$ is superior to $X_w$-1. If, $X_c$ is inferior to $X_w$-1, a shrinkage process is used to reduce the size of the simplex by moving all but the best vertex towards the best vertex (Kazmierczak, 1991:197). This is done as follows:

$$X_i = {}^1/_2 (X_b + X_i) \text{ for } i = 1,2,....,w \qquad (6)$$

The shrinkage process is very inefficient, because responses for all but the best vertex must be obtained and resorted. For this reason, and because it has been shown that the shrinkage operation causes some instability in the solution, the shrinkage operation was not used by Kazmierczak (1991) in his complex model algorithm. Furthermore, the expansion operation was also excluded for Kazmierczak's (1991) simplex algorithm. The expansion was excluded because it was assumed that the response surface was highly convoluted because there is usually no *a priori* knowledge about the response surface. In such cases, according to Kazmierczak (1992), expansion can send the vertex down a "valley" and significantly away from the optimum region.

Kazmierczak (1991) accounted for these problems by modifying the reflection and contraction operations so that movement does not start from the centroid ($\tilde{n}$) , but from the worst vertex $X_w$. To be precise, it can be seen from equations (3) and (5) that movement starts from the centroid (*e.g.* reflection: $X_r = \tilde{n} + \alpha(\tilde{n} - X_w)$). In such a case the shrinkage operation would prevent the vertex from flipping around the centroid. Because Kazmierczak (1991) did not include the shrinkage operation, he controlled this potential oscillation in the solution by starting movement from the worst vertex (*e.g.* reflection: $X_r = X_w + \alpha(\tilde{n} - X_w)$). According to Kazmierczak (1992), the simplex search procedure is therefore more or less always in a constant state of simplex shrinkage.

Different stopping criteria can be used to stop the search. For example, Box (1965:44) specified a conservative stopping criterion, namely that the program shall be stopped when five consecutive equal function evaluations have occurred. Nelder and Mead (1965:308-309) stopped the search when the standard error of the y's (simulation responses) was less than a pre-set value. Another way to terminate the search is to set a pre-defined size for the simplex, that is, by specifying the number of iterations (*e.g.* 50). Kazmierczak's complex algorithm terminates the search when either one of three conditions is met. One is when the simplex collapses to a single vertex. The second is when a specific number of iterations are completed, and the last is when a specific number of unsuccessful attempts have been made to improve $X_w$.

### 3.2.2 Crop-growth simulation models

Computerized crop-growth simulation models have the potential of reproducing the crop response over a wide range of irrigation-scheduling strategies for a variety of weather conditions. English (1981:921) underscores the usefulness of crop-growth simulation models in irrigation research by stating that "economic optimization of irrigation practices cannot be carried out without crop-growth simulation models."

Different crop-growth simulation models have been used to study crop growth and yield responses under different irrigation management practices. Examples include the Hill and Hanks model (Hill and Hanks, 1978) used by Bosch and Eidman (1987) to value irrigation information under conditions of unlimited water supply, and The Arkin, Vanderlip and Ritchie model (1976) used by Harris and Mapp (1986) to compare water-conserving irrigation strategies. The SOYGRO model was used by Swaney, Mishoe, Jones and Boggess (1983) to study the impact of weather on irrigation decisions. The only crop-simulation models that have been adapted for some crops under South African conditions are the PUTU models (De Jager, 1978), ACRU model (Schulze, 1984) and IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) models (CERES maize, CERES wheat, SOYGRO, and PNUTGRW) (IBSNAT, 1986).

In the IBSNAT project, researchers from several institutions world-wide participate in developing and testing the IBSNAT models. Field data from experiments conducted on 45 experimental stations in 16 countries are used in an on-going validation process. For example, the Grain Crops Research Institute for Agricultural Research, Cedara, Natal has been testing the CERES maize model for the past few years and is satisfied that it produces very reliable predictions (Mallett, Berry, Clemence and Fleischer, 1990). The validity of the CERES maize and wheat models for use in economic analyses under diverse production conditions in South Africa was also established in the previous chapter. The main reason for selecting the IBSNAT models was, however, computer language incompatibilities between the PUTU models and Kazmierczak's complex search algorithm.

### 3.2.3 The value of information

Analysis of the role of information in production is complicated, because at least four different concepts and measures of information can be found (Chavas and Pope, 1984). Firstly, information can be defined as a scalar-valued function of the probabilities. Secondly, information can be measured by constructing an information matrix from data provided by a sample. Information can thirdly be defined as a message which alters tastes or perceptions which are certain. The last approach, identified by Chavas and Pope (1984), entails information being defined as a message which alters probabilistic perceptions of random events. According to Baquet, Halter and Conklin (1976), this approach has the greatest appeal as a general approach, and wide potential for applications. Thus, a general procedure for valuing information is to compare outcome distributions before and after obtaining information (Bosch and Lee, 1988). More specifically, the value of information can be derived from its ability to increase the expected net returns of a firm's activities or to increase the expected utility which may result from a reduction in the firm's risks (Bosch, 1984).

Irrigation farmers, for example, may obtain different types and quantities of information. The information is then used to anticipate or trace specific state variables (*e.g.*, soil water content, plant stress or daily potential evapotranspiration ($ET_p$)). An arbitrary decision rule is applied to determine when to trigger irrigation (trigger level). Depending on the quality of the information used, it may result in an increase in the efficiency of one or more variable inputs and lead to a more desirable distribution of net returns.

Information used by decision makers can be viewed as a system with inquiry, communication, and decision components (Marschak, 1968). In order to evaluate the benefits of better information, one must assume that optimal decisions are made based on the results of the inquiry. If the decisions made are not optimal, the value of better information will be distorted (Bosch, 1984).

One way of finding the optimum irrigation decision rule for each level of information is to use specialized mathematical programming techniques, such as stochastic dynamic programming. For example, Burt and Stauber (1971), Bras and Cordova (1981) and Rhenals and Bras (1981) use stochastic dynamic programming to determine optimal rules for allocating a fixed amount of water over the season. These algorithms, however, require an analytically expressed response function and constraints for the system. In addition, these techniques often require a very specific and restrictive problem formulation (Kazmierczak and Norton, 1990).

A more flexible and realistic way of constructing the irrigated crop system is to combine simulation with some type of search procedure (Bosch *et al.*, 1987) For example, Bosch and Eidman (1987) identify the optimum irrigation decision rule for each level of information by systematically searching over a series of alternative soil-water depletion levels. They search for the optimum depletion level at 5 % intervals, by assuming constant depletion levels over the season and a constant irrigation application of 0,75 of an inch. As soon as the type of information being evaluated indicates that 45, 50, 55, or some other percentage of soil water is depleted, an irrigation of 0,75 inches is scheduled. The optimum trigger level for a decision maker is then selected, using GSD and compared to similarly obtained decision rules for other information levels. Bosch and Eidman (1987) found that under conditions of unlimited water, the value of information is largely due to the attainment of near-maximum yields with less water.

The search procedure for this research is complicated by the fact that irrigation water may be limited. In some of the irrigation seasons water quotas are introduced. The assumptions made by Bosch and Eidman (1987) about constant depletion levels over the season may not be practical where the availability of irrigation water is uncertain.

Under conditions of limited water supply the irrigator must decide in which period and to what extent the plant must be stressed in order to use the limited water most efficiently. Irrigation-scheduling strategies that deliberately apply irrigation water at depletion levels where maximum plant-growth conditions cannot be sustained, for the purpose of increasing profitability or saving water (due to limited water supplies) are generally known as deficit irrigation (Martin and Van Brocklin, 1985:1). Stockle and James (1989:86) studied the factors that affect deficit irrigation levels at which profits are maximized. They concluded their research by identifying physical soil properties, pumping height, uniformity of application and the ratio of commodity prices to production cost as the most important factors.

When practising deficit irrigation it is important that irrigation water should be applied in such a way that net returns per unit of water are maximized (Stockle and James, 1989). Maximization is done by carefully managing the timeliness and quantity of irrigation water. There are a large number of combinations of soil water depletion amounts and irrigation amounts which make it difficult to find the decision rule which maximizes the value of information.

### 3.2.4 Implications from the literature review

The approach where outcome distributions before and after obtaining information are compared, is a general and widely used procedure for valuing information. The value of irrigation information is derived from the ability of information to provide a more desirable distribution of net returns from a farming operation.

Irrigation information is obtained from inquiries made by farmers about the soil water, plant and/or weather environment. The quantity, quality and type of information obtained differ. *The obtained irrigation information is used to determine when to trigger irrigation.*

Responses to different irrigation-information levels (strategies) under conditions of uncertain weather, soil water, plant development and other variables, can best be estimated by using crop-growth simulation models. Although crop-simulation models reproduce the dynamic irrigation environment, they must be combined with a method of systematically searching over all possible implementations of a specific information level to find the optimal irrigation scheduling rule, depending upon the irrigator's goals.

The research problem lends itself to the use of an optimizing algorithm, because the simulation response cannot be expressed analytically in terms of the decision rules. The decision rules used by irrigation farmers are the percentages of potential PESW allowed to be depleted in each of the different plant-growth stages before an irrigation is scheduled (trigger level).

The research problem is expected to have many near-optimal solutions. If the response function cannot be expressed analytically there is no specific test for optimality. Therefore heuristic search procedures are used. One approach to ensure optimality is to do multiple runs with the simulation optimizing model and select the best from the simulated values. To accomplish multiple optimized values, the vertices in the initial simplex of the complex model must be selected randomly. This enables the search for an optimum to move along different depletion paths each time the search procedure is rerun and ensures that an optimal value is found.

A representative farm environment and farm net returns should be used to calculate and compare the before-tax net income (BTNI) distributions resulting from different levels of information, because farm returns are likely to be of most concern to decision makers (Bosch, 1984).

## 3.3 EMPIRICAL MODEL

The procedure to demonstrate a comprehensive dynamic approach for the optimization of irrigation management decisions under biological plant-growth conditions, requires the linking of the optimization, irrigation, biological, and economic components as described in Section 3.3.1.

Irrigation-information strategies used to determine what irrigation farmers can and are willing to pay to obtain more sophisticated information are described in Section 3.3.2. In order to value irrigation information a representative irrigation farm in the Winterton area was constructed (Section 3.3.3). The construction of a representative farm requires specification of the fixed- and variable-resource situation, the selection of irrigation-information levels, and the identification of the principal-performance measure.

In Section 3.3.4 the expected value of the BTNI distribution is defined as the principal-performance measure used in the SIMCOM model to determine the value of information for each information strategy, water availability scenario (unlimited and limited water) and soil type (different plant extractable soil water).

The efficiency of the simulation optimization model (SIMCOM) is demonstrated in Section 3.3.5 by optimizing the EV(BTNI) generated from using the irrigation-information strategy under conditions of unlimited and limited water supply.

The value of information was determined by comparing the optimized expected BTNI distributions for the different irrigation-information strategies.

### 3.3.1 Crop-growth complex model linkage (SIMCOM model)

The overall empirical model was formulated as four distinct components: the optimization, irrigation, biological crop growth, and economic components. The four parts of the

SIMCOM model were linked through a series of operational relationships. Figures 3.1 to 3.3 explain these relationships in a schematic form.

The complex method was adjusted to suit the objectives of this research. The complex model was first adjusted to maximize the expected before-tax net income values obtained from the different irrigation-information scenarios. The risk preferences of irrigation farmers in the Winterton area were ignored in the analysis, because absolute risk-aversion coefficients for farmers in the research area had not yet been elicited. Consequently, risk neutrality was assumed.

The number of decision variables optimized was changed to three. Decision variables $X_1$, $X_2$ and $X_3$ represent the trigger levels in three different plant-growth stages of maize between emergence and physiological maturity. The first plant-growth stage (stage 1) includes the emergence, juvenile and tassel plant-growth phases. The second (stage 2) is the silk and initial grainfilling phases, and the third growth stage (stage 3) includes the grainfilling and physiological maturity phases. The decision variables represent the percentage of the potential extractable soil water (PESW), as traced by the specific type of information used, that can be depleted before irrigation water is applied. These decision variables were forced to take on integer values between 20 and 100 % of PESW. Thus, PESW can be depleted by either 20, 21, ..., or 100 %. The specified decision variable ranges were selected because values outside the specified ranges are unlikely to fall in the optimum solution. The upper range of 100 % was selected because if the information used by the farmer suggests that there is no water left in the soil profile, an irrigation will be triggered, notwithstanding the fact that the actual soil-water levels may still suggest that soil water is not limited.

Although the SIMCOM model is capable of also optimizing the application amount for each of the growth stages, a fixed irrigation amount is used when irrigation is triggered. The reasons are, firstly, that the application amount does not greatly affect the distributions of net returns (Nielson, 1982). Secondly, the search for an optimum is unnecessarily complicated by optimizing twice the number of decision variables.

The optimization (Figure 3.1) starts by assigning random values, within the specified ranges, to the soil depletion levels for stages 1, 2 and 3 ($X_1$, $X_2$ and $X_3$) which form the first vertex. The complex subroutine then calls for the response resulting from the suggested vertex. The CERES maize crop-growth simulation model (Pascal version) was linked and used to simulate the response from the suggested depletion levels.

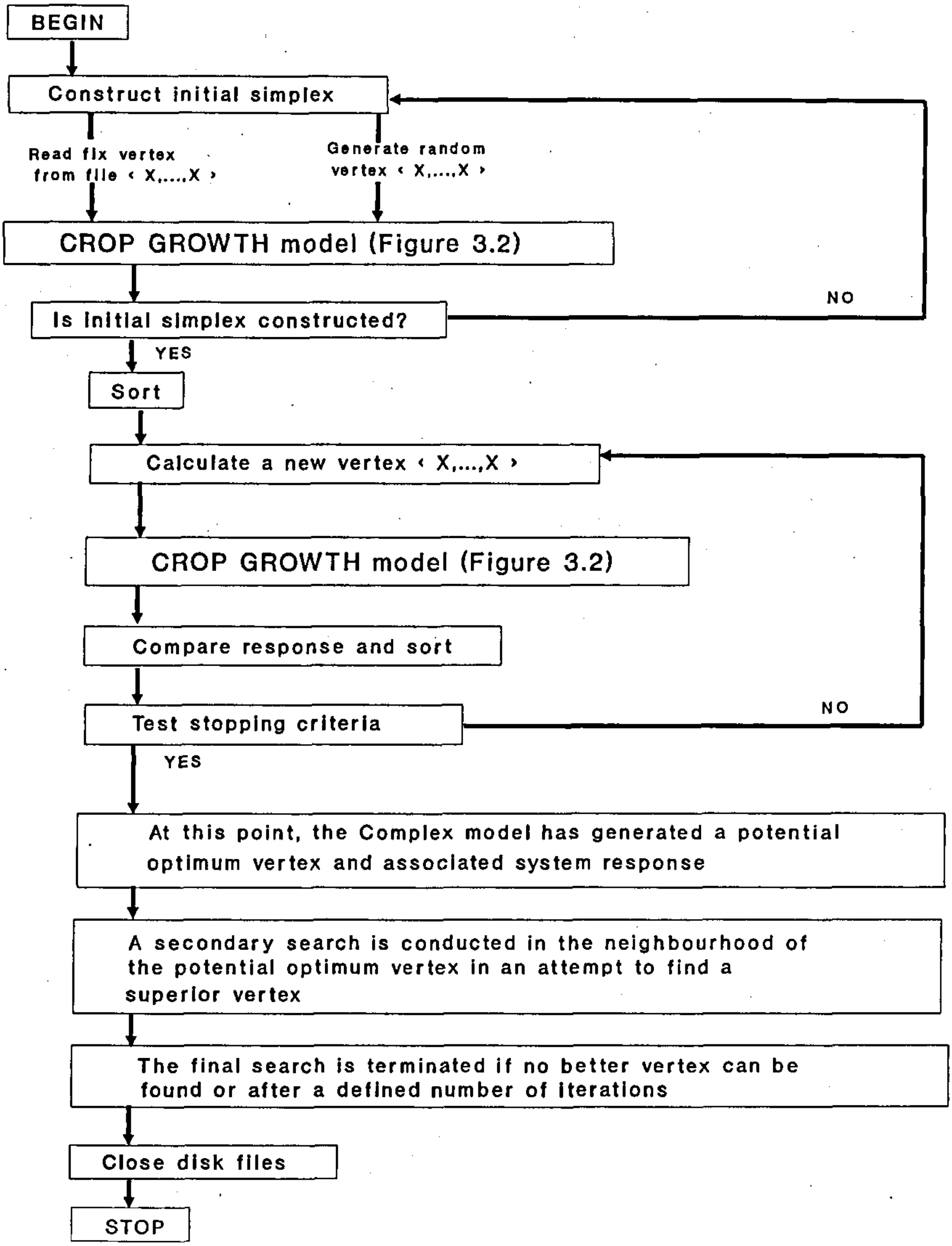


Figure 3.1 Flow chart of the SIMCOM model used to search for optimal strategy by irrigation-information level

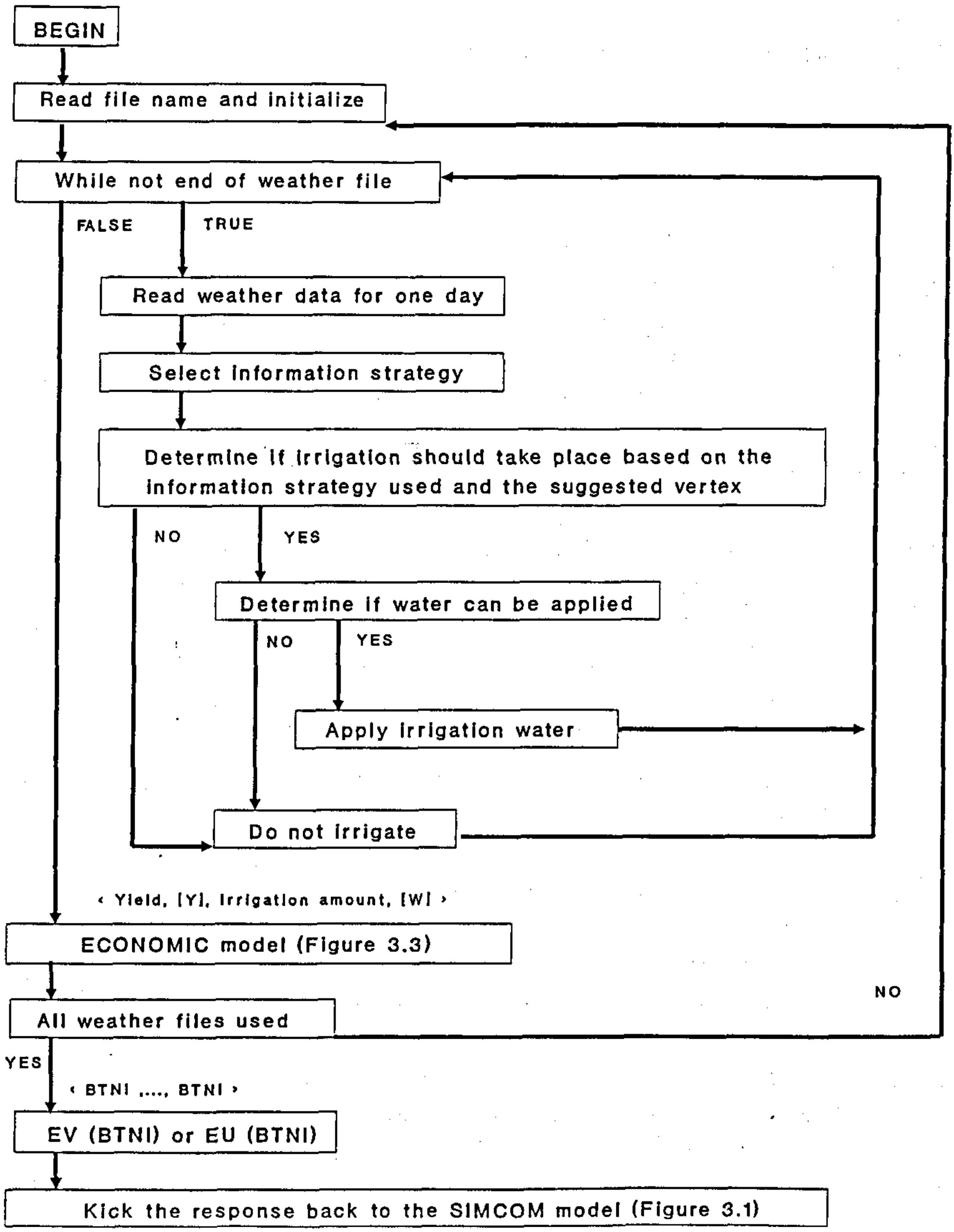


Figure 3.2 Flow chart of the crop-growth simulation model used in the SIMCOM model to simulate the responses for different irrigation-information strategies

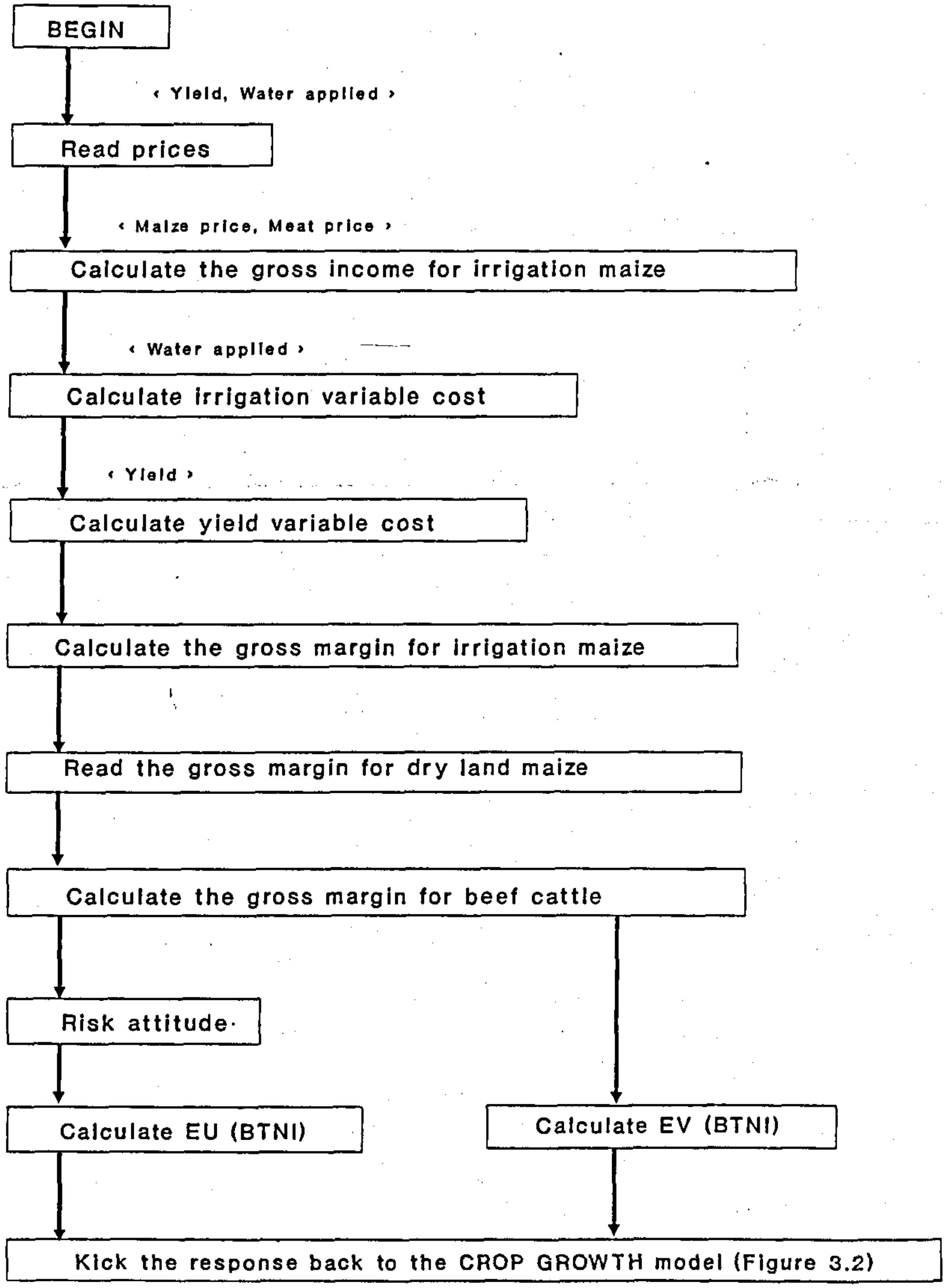


Figure 3.3 Flow chart of the economic model used in the SIMCOM model to calculate the expected utility (or expected value) from yield responses and water applied simulated by the crop-growth simulation model

The crop-growth simulation model (Figure 3.2) starts by initializing all the soil, crop and weather variables. It continues by reading the first line of weather variables for the first year of weather data. From these variables it calculates the soil-water, plant-growth and weather variables. These variables, along with the suggested values for the first vertex, are then read into an irrigation scheduling subroutine where the following procedures take place: First, an irrigation-information strategy is selected according to a specific flag value as specified in the input parameter file. Next, the trigger level for the specific plant-growth stage is selected from the array of decision variables suggested in the first vertex. The soil-water level according to the specified information level is calculated next and compared to the selected trigger level. If the calculated soil-water level is less than the selected trigger level, an irrigation is scheduled. In such a case, an effective application amount of 10 mm is selected. The irrigation water is applied the following day. The reason is that it takes at least a day for the centre pivot irrigation system to complete half the circle.

When the decision is made to irrigate, two days are allowed for the centre pivot to apply the scheduled 10 mm of irrigation water. Another decision to irrigate cannot be made while the irrigation system is still applying water.

After determining whether irrigation should take place, the crop-growth simulation model reads the next day's weather data. The process repeats itself on a daily basis until the end of the growing season. If water supply is limited, irrigation water is applied until all the available water has been used; after that, the application amount is set to zero.

The simulated yield and the amount of irrigation water applied during the specific year are then introduced into an economic subroutine (Figure 3.3). Random output prices for the main enterprises are selected. The income, as well as the cost resulting from the specific yield, and irrigation amount are calculated. The income from and costs of other enterprises on the representative irrigation farm are also calculated and processed to obtain a BTNI value for the specific information scenario and weather year (a detailed discussion of the calculation of BTNI is presented later in the chapter).

The same process is repeated for each of the weather years used in the analysis. The BTNI values obtained from the different years are then used to calculate the expected value for that specific vertex, assuming equal probability of occurrence for the different weather years.

The whole process is repeated 10 times to establish the initial simplex. The vertices and their corresponding expected values are then sorted from the best vertex (highest expected BTNI value) to the worst. The actual optimization process begins after the sorting process with the calculation of a new vertex. The expected BTNI value from the new vertex is calculated in a similar fashion and compared to the other vertices already in the simplex. If it results in a higher expected BTNI value, then the worst vertex is replaced, and a new vertex is again suggested. This process of moving the simplex through the viable region is in accordance with the specified constraints and characteristics of the production surface. The movement of the simplex continues until no better vertex can be found (*e.g.*, suggesting an given amount of vertexes without improving the search) or the search procedure reached 150 iterations.

The program was coded in Turbo Pascal using the object-orientated programming style. The program allows for a variety of different operating procedures. Therefore, it is important to select the correct operating procedures by setting different flag values. For example, the program can be made either to optimize or not to optimize. This can be done by changing the OPTIMIZE flag value to either true or false. The program, when the OPTIMIZE flag value is set to false, will only simulate responses for specific trigger values as described by the user. The program also includes the option of optimizing the net returns for a single crop or of optimizing the BTNI for a representative farm. The switch between optimizing single crop net returns or BTNIs may be effected by setting the CAL_BTNI flag value to either false or true, respectively. In addition, the program includes the option of starting the initial simplex from a fixed initial simplex as described by the user. This option can prove very efficient if the user has prior knowledge of the nature of the production surface, because it will step up the convergence speed of the search. This operating procedure can be used when the RANDOM_GEN flag value is set to false and a file is provided where all the vertices which must be included in the initial simplex are specified. Lastly, the program includes the option of doing a double search. This option can prove helpful if the convergence properties of the response surface are very low. In such a case, the final simplex of the first search is used as the initial simplex for the next search. This option is selected by setting the DOUBLE_OPT flag value to false.

Other important variables that must be set before optimizing are the reflection coefficients (REFLECT, $\alpha$, Equation 4) and DELTA. REFLECT determines how far along the vector the new vertex will be established in a single reflection. DELTA is the step size and is used to modify the movement along the vector. The DELTA coefficient forces the movement to take place in discrete steps only. Kazmierczak (1991) suggests that

REFLECT should be one half the level of DELTA. After testing the SIMCOM model, it was decided to set DELTA equal to 5 and REFLECT equal to 2,5.

Lastly, apart from specifying all the economic parameters of the enterprise identified on the representative farm, the number of decision variables (variable in program called DECISION) that are optimized, and the number of vertices (variable in program called NUMVERTICES) in the initial simplex must be specified. The variables called DECISION and NUMVERTICES were set equal to 3 and 10, respectively.

### 3.3.2 A representative farm in the Winterton area

A representative farm with irrigated, dry-land, livestock and pasture enterprises was constructed from survey results obtained in the Winterton area. The representative farm was used to evaluate the effects and determine the value of more sophisticated irrigation-scheduling information. A detailed discussion of the procedures used in the construction of the representative farm, as well as the budgeting procedures and the enterprise budgets, is presented in Appendix B.

A questionnaire obtaining information about the farmer, farm business, fixed and variable resources, financial situation and production systems was administrated on a personal basis to 53 irrigation farmers in the Winterton area. Frequency distributions were used to first categorize farms in terms of the number of hectares under irrigation. The number of hectares under dry-land and grazing were next identified for each of the irrigation size intervals selected. After identifying the representative fixed-resource structures, variable resource structures were identified. Group discussions and expert opinions were predominantly used. The financial structure of the farm was determined next. Lastly, a representative production system was identified. Group discussions were again held to construct enterprise budgets for each of the enterprises in the selected production system.

The constructed farm consists of 550 owned hectares, comprising 50 ha dry-land, 200 ha irrigation and 300 ha grazing. Of the 200 ha irrigation, 170 ha are used to cultivate cash crops, and the remainder (30 ha) for irrigated pastures. After group discussions with farmers and extension officers, it was decided that a representative production system for these fixed resources would be a beef-production system and the production of dry-land and irrigation maize. Maize, maize stubble and kikuyu/ryegrass pastures are utilized, in addition to the grazing, by the beef-production system.

The cash crops are irrigated by two 60 ha and one 50 ha centre pivot systems, designed to irrigate soils with a relatively high clay content (45 %), with a gross application capacity of 6,5 mm/day. Given an 80 % application efficiency, 5,2 mm/day can be applied effectively. Survey results indicate that most of the centre pivot irrigation systems work at an average pumping height of 40 metres. The 30 ha kikuyu/ryegrass pastures are irrigated with a drag line system. The drag line system is designed for a gross application capacity of 4 mm per 24 hours.

An Avalon/Bergville soil with a rooting depth of 800 mm and a plant extractable soil water content (PESW) of 77 mm were selected for the production of the dry-land maize. Two soils were used for the production of irrigation maize. The analyses were done on soils that differ in terms of PESW to account for the variability in irrigated soils, and to determine the effect of PESW on the value of irrigation information. It was assumed that the soil under irrigation was the Hutton/Doveton soil with a rooting depth of 1 050 mm and PESW of 138 mm. The analyses were repeated on the Avalon/Bergville soil with a PESW of 77 mm. The same irrigation system was used to irrigate both soils, because the selected soils had similar clay contents (45 %), and therefore comparable infiltration ratios.

Group discussions with farmers and extension officers revealed that farmers using no or little irrigation information apply between 300 to 350 mm of effective water on maize if irrigation water is available in unlimited quantities. The effect of limited water on the value of information was evaluated assuming irrigation water was limited to an effective 150 mm/ha (1 500 $cm^3$/ha). This amounts to about a 50 % reduction in the amount of water available for irrigation. Assuming an 80 % irrigation efficiency, 1 800 $cm^3$/ha of water were available per irrigated hectare.

Overhead cost is categorized as depreciation, insurance, interest and other miscellaneous overhead expenses. The cost of each category was calculated and presented in four tables (B2 - B5) located in Appendix B. Depreciation, insurance, interest and other miscellaneous overhead expenses were calculated as R140 439, R23 116, R137 576 and R100 173, respectively. Total overhead cost therefore amount to R401 304.

From the questionnaire used to construct the representative farm (see Appendix B) it was determined that few irrigation farmers with similar fixed resources to those of the representative farm receive off-farm income (OFI).

Enterprise budgets for the major enterprises on the representative irrigation farm were drawn up from group discussions held with irrigation farmers in the Winterton area. Enterprise budgets for dry-land and irrigation maize are presented in Tables B6 and B7. Production costs (PC) for dry-land and irrigation maize were calculated as, respectively, R822 and R1 198. The production cost for irrigated maize was not adjusted under conditions of limited water supply, because of the area's high maize yield potential, even under dry-land conditions. Irrigation and harvesting costs were excluded when PC was calculated, because these costs were included in the calculation of IC and YC, respectively. IC and YC change with changes in the simulated yield and irrigation water amounts. The IC for the centre pivot irrigation system was estimated by using a computerized irrigation cost program developed by Meiring (1989). IC cost was calculated for the specific production and irrigation conditions as 64 cents per millimetre water applied per hectare. Harvesting cost was calculated by multiplying the variable cost of the harvester per hour (R54,78/hour) by the harvesting speed (hours/ha), which was a function of the simulated yield. Transportation cost was calculated at R0,154/ton/km. The nearest grain silo was taken to be approximately 30 km away.

The beef enterprise on the representative farm consists of a 100 cow-calf unit production system, 60 head of cattle being bought each November to utilize the kikuyu/ryegrass pastures and an additional 100 head of cattle being bought each July to utilize the maize stubble. Both the 60 and 100 cattle groups are bought for speculation purposes. They are fattened and sold about three months later. The enterprise budget for a 100 cow beef herd and 60 head of cattle bought for speculation cattle are presented in Table B8, while the enterprise budget for 100 head of cattle bought for speculation are presented in Table B9 (Appendix B). Production cost for the cow-calf production and the 60 speculation cattle amounts to R70 117. Eight hundred kilograms of maize per head of cattle are transferred from the irrigation maize to the beef enterprise to fatten calves in a feedpen. In other words, production cost is calculated on the produced maize, but the amount of maize sold is reduced by the amount of maize transferred to the beef enterprise. The production cost for the 100 speculation cattle on the maize stubble was calculated at R8 541.

### 3.3.3 Information levels

Different irrigation-information scheduling scenarios were constructed using different levels of soil-water, plant-growth and weather information. Irrigation information is defined as the information obtained by the farmer by measuring, tracking and/or making informed assumptions about soil-water, plant-growth and weather conditions during specific time periods in the growth season. Information is the real-time data a farmer needs to decide whether to irrigate or not.

Different levels of soil-water, plant-growth and weather information were identified for purposes of this research. Three levels of soil-water information were used. The first level of soil-water information is where no or little soil-water information is provided. The second level of soil-water information is intermediate information about the daily soil-water levels. The intermediate level of soil-water information is set with an estimation error not exceeding plus or minus 15 % of the PESW of the soil, to place it approximately midway between the low and perfect soil-water information levels. The third level of soil-water information is perfect information about the daily soil-water levels.

Two levels of plant-growth information were used. The first level of plant-growth information is information about the timing and duration of the different crop-growth stages only. This minimum level of information is assumed, because the timing and duration of the plant-growth stages are of critical importance under deficit irrigation *conditions. Deficit irrigation therefore cannot be practised without, at least, this basic* level of information. The second level of plant-growth information is sophisticated daily plant-growth information. Scenarios include information on plant growth (the development of the plant in terms of leaf area ) that will take place in the next three days. This plant-growth information is used in conjunction with weather information to calculate the amount of water that will evapotranspirate (ET) over the next three days if water is not limited, that is, the amount of water lost through the plant (transpiration) plus the amount of water lost from the soil surface (evaporation).

Three levels of weather information were used. The levels of weather information included were first, no or little weather information. The second level of weather information is knowledge about daily potential evapotranspiration (Eo) for a particular day, *e.g.*, the amount of water that can, potentially, be taken up by the atmosphere. The third level of weather information is perfect information about the amount of ET and/or rainfall that will occur over the next three days.

Six irrigation-information strategies were formulated by using different combinations of the identified information levels. The different soil-water, plant-growth and weather information levels used by the irrigation-information strategies are summarized in Table 3.1. Table 3.1 will also be referred to in the discussion of the individual strategies that follows.

Table 3.1 A summary of the different levels of soil-water, plant-growth and weather information used by the six formulated irrigation-scheduling strategies

| Soil-water information | Strategy 1 | Strategy 2 | Strategy 3 | Strategy 4 | Strategy 5 | Strategy 6 |
|---|---|---|---|---|---|---|
| 1. No or little | X | X(4) | - | - | - | - |
| 2. Intermediate(1) | - | - | X | - | - | - |
| 3. Perfect | - | - | - | X | X | X |

| Plant information | Strategy 1 | Strategy 2 | Strategy 3 | Strategy 4 | Strategy 5 | Strategy 6 |
|---|---|---|---|---|---|---|
| 1. Intermediate(2) | X | X | X | X | X | - |
| 2. Perfect | - | - | - | - | - | X |

| Weather information | Strategy 1 | Strategy 2 | Strategy 3 | Strategy 4 | Strategy 5 | Strategy 6 |
|---|---|---|---|---|---|---|
| 1. No or little | X | - | X | X | - | - |
| 2. Intermediate(3) | - | X | - | - | - | - |
| 3. Future rainfall | - | - | - | - | X | X |
| 4. Future ET | - | - | - | - | - | X |

1. The intermediate level of soil-water information assumed that soil water was estimated with random error not bigger than 10 % of the PESW.
2. The intermediate level of plant growth assumed knowledge about the timing and duration of the different growth stages.
3. The intermediate level of weather information assumed daily information about Eo.
4. Strategy 2 provides less soil-water information than Strategy 3 (intermediate soil-water information) but more than the no-soil-water information used in Strategy 1.

### 3.3.3.1 Irrigation-Information Strategy 1 (No-information)

A no-information irrigation strategy (Strategy 1) was used as a benchmark strategy against which to compare more sophisticated information strategies. The Delphi technique, combined with group discussions, was used to formulate a no-information strategy, so that it reflected the irrigation decisions made by irrigators who use little or no soil-water, plant-growth and weather information.

The different levels and types of irrigation information used by strategy 1 are summarized in Table 3.1. The no-information strategy uses no formal measuring method to determine when to irrigate, but applies enough irrigation water to minimize the chance of plant-water stress occurring during the growth season. Rainfall is not utilized very effectively and is only taken into consideration to postpone irrigation.

An open-ended questionnaire was sent to 53 irrigation farmers in the Winterton area, asking them to formulate an irrigation-scheduling strategy for maize that uses very little or no soil-water, plant-growth and weather information under conditions of unlimited and limited water supply. The scenario used to describe the limited water supply condition was one where the amount of water applied under unlimited water supply conditions was reduced by about 50 %. The response was disappointing, only 32 % of the questionnaires were returned. In addition, the irrigation-information strategies were poorly formulated, resulting in only 8 % eventually being used. It was decided to incorporate the expertise of an irrigation expert running a scheduling service in the area. Another questionnaire was drawn up and send to Roy Mottram along with all the responses of the farmers. He was asked to use the responses obtained from the farmers, his knowledge of irrigation practices in the area and his own expertise to formulate a no-information irrigation strategy for maize under unlimited and limited irrigation water supply conditions. The parameters of his no-information strategy, like irrigation amount and adjustments made to application amounts and time duration between irrigations, were verified by farmers and other experts in the area. The guidelines presented in the no-information strategy formulated by Bosch (1984) were also used to test and adjust the formulated no-information strategy.

The no-information strategy assumed that irrigation farmers have a good idea of rising water demand as crop-growth progresses and an increasing sensitivity to plant-water stress. Consequently, farmers will decrease the time between irrigations as the season progresses, but will keep the application amount per irrigation throughout the growth season constant. It was also assumed that the irrigation farmers have information about the timing and duration of the different plant-growth stages. However, plant growth was only divided into three stages. The main characteristics of the no-information irrigation scheduling strategy for maize under conditions of unlimited and limited water supply are presented in Table 3.2.

From Table 3.2 it is clear that the no-information strategy under unlimited water supply conditions will start by applying an effective 10 mm of irrigation water every three days over the period from germination to tassel. The irrigation cycle shortens to a two-day cycle in the silk to initial grainfilling phases. The irrigation cycle is again lengthened to three days in the end grainfilling to physiological maturity phases. Each time irrigation is triggered, an effective 10 mm of water is applied. However, if the rainfall during the previous three days exceeds 15 mm, the irrigation is postponed by one day. In following the no-information strategy over the 20 weather years used in this research, farmers will apply between 280 and 320 mm (effective) irrigation water per hectare. This is comparable to an irrigation amount of 300 mm/ha used by the Department of Agriculture

(1993) in the construction of enterprise budgets for maize irrigation in the Bergville/Winterton area, and to the 300 to 350 mm/ha ascertained from group discussions held with irrigation farmers in the Winterton area.

Table 3.2 The no-irrigation information strategy constructed for the irrigation of maize in the Winterton area under conditions of limited and unlimited water supply, 1993

| GROWTH STAGES | UNLIMITED WATER SUPPLY | | LIMITED WATER SUPPLY | |
|---|---|---|---|---|
| | Irrigation amount (mm) | Irrigation cycle (days) | Irrigation amount (mm) | Irrigation cycle (days) |
| Stage 1[(1)] | 10 | 3 | 5 | 6[(4)] |
| Stage 2[(2)] | 10 | 2 | 10 | 4 |
| Stage 3[(3)] | 10 | 3 | 10 | 6 |

1. Stage 1 is from germination to tassel.
2. Stage 2 is from silk to initial grainfilling.
3. Stage 3 is from end grainfilling to physiological maturity.
4. In growth stage 3, for example, irrigation is triggered every six days. When an irrigation is triggered, an irrigation amount of 5 mm is applied, except if the rainfall over the previous three days has exceeded 15 mm. In such a case, the irrigation is postponed by one day.

The no-information irrigation strategy used under conditions of limited water supply is also presented in Table 3.2. Under conditions of a 50 % reduction in irrigation water supply, the application amount in the first growth stage (germination to tassel) is reduced to 5 mm and the irrigation cycle is lengthened to six days. In the following two growth stages the irrigation cycle is doubled from what it was when water was not limiting. In other words, the irrigation cycle in the tassel to initial grainfilling growth phase changes from a two- to a four-day cycle, and in the end grainfilling to physiological maturity stages from a three- to a six-day cycle. Each time irrigation is triggered in these two stages an effective amount of 10 mm is applied. Again, when the rainfall during the previous three days exceeds 15 mm the irrigation is postponed by one day. In following this strategy for different years, farmers will apply between 130 and 170 mm of effective irrigation water per hectare. However, in years when the rainfall is below normal (years when 170 mm is applied) no irrigation water was scheduled when the allocated 150 mm water was depleted.

#### 3.3.3.2 Irrigation-Information Strategy 2 (Checkbook)

Weather information is also frequently used by irrigators to schedule irrigation water. For example, irrigation farmers may use the evaporation pan to estimate potential evapotranspiration (Eo). The daily Eo estimates are then multiplied by an appropriate crop coefficient (kc) to obtain the daily potential plant evapotranspiration (ET) when water is not limited (see Equation 7).

$$ET = kc * Eo \tag{7}$$

where

| | | |
|---|---|---|
| ET | = | evapotranspiration; |
| kc | = | crop coefficient, and |
| Eo | = | potential evapotranspiration. |

Strategy 2 uses no or limited soil-water information, while an intermediate level of plant-growth and weather information are assumed (Table 3.1). The plant-growth and weather information is information about the timing and duration of the different growth stages, and knowledge about average daily potential evapotranspiration demand (Eo), respectively.

Strategy 2 is similar to a checkbook method. According to Werner (1978), irrigation farmers following the checkbook method begin by gathering information about the initial soil water condition. They judge the soil's water content by feel or appearance of the soil, or some other way of estimating soil water. Daily Eo values are obtained and multiplied by the appropriate kc-coefficients. The kc-coefficients used in this research to estimate the daily ET in the three different growth stages were 0,7; 1,0 and 0,9. The kc-coefficients were obtained from Mottram (1982). The irrigation farmer will then track the soil water by keeping account of the soil-water levels. This is done by subtracting the daily approximated ET values and adding rainfall and irrigation to the soil-water levels (Bosch, 1984).

After determining the initial soil-water level, a daily soil water budget is kept by recording the daily ET, rainfall and irrigation amounts. The estimated daily soil-water level is compared to the suggested trigger level obtained from the optimization procedure. Irrigation is applied if the estimated soil-water level drops below the suggested trigger value.

Werner (1978) advised farmers following his checkbook-irrigation strategy to make periodic checks of actual soil-water levels during the season. The soil water checks are used to correct the soil-water level. Weekly corrections of the soil water, as well as the initial estimates of the soil-water levels were simulated by assuming that farmers used the feel and appearance method. According to Merriam (1960), the feel and appearance method, can result in an estimation error in the range of 17 mm per metre of soil profile (0,2 of an inch per foot of profile (Bosch, 1984)). It was decided to work with an estimation error of 20 mm per metre of profile. The mid-point value of 10 mm was used to round off to the nearest 10 mm the daily soil-water levels, as calculated by the CERES maize model. In other words, if the farmer inspects the soil-water levels, he will adjust the soil-water level as calculated by the checkbook method to within 10 mm of the actual soil-water levels. For example, if the actual soil-water level is somewhere between 0 and 20 mm, the program will adjust the checkbook soil water estimate to 10 mm.

Limits were placed on the number of errors allowed when using the checkbook method, because farmers may use the feel and appearance method to correct soil-water levels. For this reason, soil-water levels were corrected every seven days according to the specified criteria (Werner, 1978). In addition, soil-water levels were corrected if the soil was saturated above the PESW from a rainfall of more than 25 mm. In such an event, soil-water levels were corrected to the upper limit of PESW.

#### 3.3.3.3 Irrigation-Scheduling Strategies 3 and 4

Both Scheduling Strategies 3 and 4 base irrigation-scheduling decisions on soil-water information, while no or limited plant-growth and weather information are used (Table 3.1).

Strategy 3 provides irrigation farmers with intermediate soil-water information only, because daily soil-water levels cannot be measured accurately. The intermediate soil-water information provided by Strategy 3, however, is more than the little soil-water information provided by Information Strategy 2. The reason is that the feel and appearance method used in Strategy 2 provides the irrigator with very little soil-water information because it is less accurate and is used on a weekly basis only.

Soil water estimation errors are made by irrigators because of measurement and sampling errors. Bosch (1984) assumes that soil water estimation errors are uniformly and randomly distributed and do not exceed 10 % of the PESW. However, the estimation error used in this research was changed to 15 % to reflect more realistic estimation errors for the less uniform soil in the Winterton area. As a result, Strategy 3 assumed that the daily soil-water levels were measured with an estimation error not greater than 15 % of the PESW. The estimation error was assumed to be uniformly and randomly distributed.

In contrast, Strategy 4 uses perfect daily soil-water information. Soil-water levels as calculated by the crop-growth model are used. Although this information level is probably not attainable given the present technology, it was included to show the increased return from such technology.

#### 3.3.3.4 Irrigation-Scheduling Strategies 5 and 6

Irrigation-Scheduling Strategies 5 and 6 are similar to Strategy 4, as regards the use of perfect soil-water information. In addition to Strategy 4, however, Strategy 5 provides the irrigator with perfect information about future rainfall. Strategy 6, in addition to the information provided by Strategy 5, provides farmers with information about the plants' leaf area (perfect plant-growth information) and, consequently, the future ET demand (perfect weather information). This experimental design will value future ET information, given that future rainfall information is already known, determining whether additional efforts should be made to provide the farmers with perfect information about plant growth, if water is not limited, if they already have perfect information about the soil water and the future rainfall.

Strategy 5 uses perfect soil-water, intermediate plant-growth and weather information. The irrigator receives information about the amount of rain over the next three days. The future rainfall values are obtained by adding rainfall for that day to rainfall for the next two days. This is done for all the days in the growing season, and for all the weather years. An irrigation is scheduled when the soil water content plus the future rain values drop below the suggested trigger level obtained from the optimization procedure for each of the plant-growth stages.

Like Strategy 5, Strategy 6 uses perfect soil-water, perfect plant-growth, future rainfall and ET information over the next three days. Therefore, irrigation decisions can be made by also considering the status of the crops that will not be reached before the next irrigation is scheduled. The future soil water content of the field is calculated by subtracting the future ET values from the daily soil-water levels and adding the rainfall over the next three days. Irrigation water is applied when future soil-water levels drop below the trigger levels obtained by the optimization procedure for each of the plant-growth stages.

Future ET values are obtained by running the crop-growth model for each of the weather years and soils. The three-day ET values for each day in the growth season are then calculated by adding the ET value for that day to ET values simulated for the next two days. These summed values are written to the weather files. The future ET values are read by the crop-growth simulation model on a daily basis along with the other weather variables.

By comparing Strategies 5 and 6 with the other irrigation-scheduling strategies, the value of providing irrigation farmers with perfect plant-growth and future weather estimates can be determined.

For the purpose of this research, the flag value in the input parameter file was changed to either 0, 1, 2, 3, 4, 5, or 6 to force the irrigation subroutine to use only the relevant procedures applicable to the specific type and quantity of information used. When an 0 was selected, the model was run under dry-land conditions.

### 3.3.4 The principal-performance measure

The SIMCOM model was programmed so as to maximize the expected value of a before-tax net income distribution (EV(BTNI)) for each of the information strategies on the representative irrigation farm. The BTNI distribution for a specific information strategy on the representative farm was simulated using 20 years' weather data. The EV(BTNI) was calculated as follows:

$$EV(BTNI) = \sum_{i=1}^{20} [(NR_{im} + NR_{dm} + NR_{bc} - OC) * Pr] \qquad (9)$$

The BTNI for a specific weather year was calculated by totalling net returns received from beef cattle ($NR_{bc}$), dry-land maize ($NR_{dm}$) and irrigated maize ($NR_{im}$). Overhead cost was then deducted. The calculated BTNI for that specific year was multiplied by the probability of occurrence (Pr), and added to the BTNI values calculated in similar fashion for each of the 20 years. The 20 years' weather data were obtained from a weather station in the research area and included daily values of minimum and maximum temperature, rainfall and sunshine duration. It was assumed that any one weather year has an equal probability of occurring. A Pr value of 0,05 was therefore used in the calculations.

The NR for the dry-land maize and beef cattle enterprise, as well as OC remains unchanged regardless of changes between the different irrigation-information strategies.

However, $NR_{bc}$, $NR_{dm}$ and OC are included in the calculations, because the income generated from these enterprises may be correlated to the value of information.

$NR_{bc}$ was calculated as follows:

$$NR_{bc} = \sum_{i=1}^{20} [\{(Y_b + Y_{s1} + Y_{s2})^* P_{bi}\} - PC_b - PC_{s1} - PC_{s2}] \qquad (10)$$

where the variables present the kilograms beef produced annually from the cow-calf production system ($Y_b$), the weight gain by the two groups of speculation cattle bought annually ($Y_{s1}$ and $Y_{s2}$), the beef price in a specific year ($P_{bi}$) and the production cost for the cow-calf production system and two groups of speculation cattle ($PC_b$, $PC_{s1}$ and $PC_{s2}$).

$NR_{dm}$ was calculated as follows:

$$NR_{dm} = \sum_{i=1}^{20} [\{(Y_i * P_i) - PC - YC_i\} * A] \qquad (11)$$

where the variables represent: yield (Y), output price (P), production cost for dry-land maize (PC), yield variable cost (YC) for the different replications (i), and area planted (A).

On the other hand, $NR_{im}$ changed with weather and irrigation-information strategies. $NR_{im}$ was calculated as follows:

$$NR_{im} = \sum_{i=1}^{20} [\{(Y_i * P_i) - PC - IC_i - YC_i\} * A] \qquad (12)$$

where the variables represent: yield (Y), output price (P), production cost for irrigation maize (PC), irrigation variable cost (IC), yield variable cost (YC) for the different replications (i), and area planted (A).

Important stochastic variables in Equation 12 are the Y, P, IC and YC. Y, IC and YC are stochastically varied, depending on the yield and irrigation water used. Production risk is reflected in the variable yields and water amounts simulated under different information strategies, weather conditions and decision variables. To reflect the importance of price risk in the farm decision-making environment, product prices for maize and beef are stochastically varied.

Beef prices and their corresponding probabilities were subjectively determined by using information elicited from beef farmers in the Winterton area. The maize price generating procedure formulated by Meiring (1994) was used to reflect the price risk for maize. Meiring's (1994) scenario was based on the fact that the maize price is very sensitive to the total amount of maize produced annually. Both the beef and maize price distributions were read into the @RISK program. The minimum and maximum price values, along with the other price percentile intervals, were specified. The @CUMULR function in the @RISK program was used to generate cumulative distribution functions (CDFs) for maize and beef prices. The CDFs for maize and beef are presented graphically in Figures B1 and B2 (Appendix B). Historical, deflated producer prices for maize and beef were obtained from the Meat Board. From this data a correlation coefficient of 0,3219 was calculated. A correlation matrix was set up in @RISK and used to generate 20 correlated maize and beef prices from the two CDFs. These correlated maize and beef prices are presented in Table 3.3. Each set of output prices was randomly assigned to the 20 sets of meteorological data obtained for the Winterton area (1973 to 1993). In other words, a zero correlation between the maize yields obtained in Winterton (weather years) and output prices was assumed. The reason was, firstly, that no data could be obtained from which correlation coefficients could be calculated. Secondly, the research area is relatively small and cannot affect national production figures.

A sensitivity analysis was done on the value of information by assuming a perfect negative correlation between maize yields (weather years) and maize producer prices (-1,0). This was done because maize and beef prices may actually be correlated with weather years which may again be correlated with the value of information. The correlated maize and beef price sets were rearranged so that the highest generated maize price, with its correlated beef price, was realized in the weather year with the lowest dry-land maize yield. A new price vector was not generated because higher or lower expected prices could have been generated for either or both of the price variables. The sensitivity analysis was limited only to Information Strategy 4 (perfect soil-water information) on both the soils under conditions of unlimited and limited water supply.

Net returns received from the dry-land maize enterprise were calculated first. The flag values in the SIMCOM program were set up to calculate only the net returns for each of the 20 replications. An equation similar to Equation 10 was used to calculate the net returns for dry-land maize. The only difference was that no irrigation cost was calculated, and the PC for dry-land maize, as calculated in Table B6 (Appendix B), was used. The $NR_{dm}$ for each replication was then written to 20 output files, one for each year of weather data.

Table 3.3 Correlated meat and maize producer prices randomly assigned to the 20 weather years to calculate the EV(BTNI) for a representative irrigation farm in the Winterton area, 1993

| REPLICATION | MEAT PRICE (R/kg) | MAIZE PRICE (R/kg) |
|---|---|---|
| 1 | 4,73 | 387,93 |
| 2 | 6,37 | 430,79 |
| 3 | 4,31 | 456,70 |
| 4 | 3,72 | 353,73 |
| 5 | 4,16 | 366,38 |
| 6 | 4,23 | 379,93 |
| 7 | 3,57 | 420,42 |
| 8 | 3,83 | 450,98 |
| 9 | 4,50 | 371,48 |
| 10 | 5,28 | 382,75 |
| 11 | 4,63 | 409,02 |
| 12 | 4,88 | 441,03 |
| 13 | 3,54 | 354,50 |
| 14 | 3,97 | 392,67 |
| 15 | 3,74 | 462,26 |
| 16 | 6,95 | 376,06 |
| 17 | 7,08 | 402,50 |
| 18 | 3,64 | 414,72 |
| 19 | 3,54 | 361,51 |
| 20 | 3,60 | 397,14 |

The simulation runs for dry-land maize were started with PESW about 45 % depleted, because the area receives little or no rainfall in the winter months prior to planting. The soil profile, therefore, had not received enough rain to fill up the profile. The planting date for dry-land maize was November 15 (day 319). The planting date for the 170 hectare irrigation maize was selected to be 10 days later (November 25, day 329) with a 55 % depleted PESW. Planting dates and depletion levels used were obtained from group discussions with irrigation farmers and agricultural extension officers working in the area.

The flag values in the SIMCOM model were then changed to allow the model to optimize total farm BTNI. The economic subroutine used the simulated yield and water amount obtained at the end of a particular season, along with the economic variables, to calculate the $NR_{im}$. The $NR_{bc}$ was calculated next. The calculated $NR_{im}$ and $NR_{bc}$ for that specific replication were then added to the $NR_{dm}$ simulated for the same weather year (read from a file). The BTNI for that specific year was obtained by subtracting OC from the summed NR values. The BTNI was multiplied by the probability of occurrence and stored. This process was repeated 20 times to obtain the EV(BTNI).

The procedure up to now has simulated the response to a specific vertex introduced for the optimization component. A next vertex, consisting of three irrigation depletion amounts for three different growth stages, will be calculated (discussed in the search procedure) and again introduced into the crop growth, irrigation and economic components. The procedure will repeat itself until one of the stopping criteria is met.

### 3.3.5 The application of the SIMCOM model

The efficiency with which the search procedure moved through the production surface was first tested using Strategy 2. The EV(BTNI) from using Information Strategy 2 was simulated 13 times using the Avalon soil and both unlimited and limited water supply conditions. To save some computer time, only weather data for 15 years were used in the test. The SIMCOM model was started with an initial simplex that was randomly selected. This enabled the search for the highest EV(BTNI) to follow different depletion paths. The optimized EV(BTNI) and trigger levels for Information Strategy 2, replicated 13 times, on the Avalon soil under conditions of limited and unlimited soil water supply in the Winterton area are presented in Table 3.4. The ability of the search procedure to converge into a single vertex was tested by calculating the mean standard deviation, coefficient of variation, and highest and lowest values from making multiple simulation optimization runs.

The 13 replications of the optimized EV(BTNI) and trigger levels of Strategy 2 all converged to nearly the same value. The coefficient of variation calculated on the EV(BTNI) for both the unlimited and limited water supply conditions was less than 1,1 %. However, the SIMCOM model was replicated five times to ensure that the best optimum for each information strategy was selected. In other words, the SIMCOM model was allowed to construct five different initial simplexes from which the search begins. The highest EV(BTNI) value from these five replications was selected for each information-soil strategy combination.

The very high depletion values used by Strategy 2, firstly, may be the result of the overestimation of the rate of soil water depletion with this information level. Although the optimal depletion levels in each of the three growth stages decreased substantially when better information levels were used, it remained relatively high. A possible explanation for the relatively high depletion levels, notwithstanding the use of sophisticated irrigation information, is the high frequency of rainfall in the area, that is, irrigation water in actual fact is not necessary until low levels of PESW are reached. Irrigation is however seen in the area as a very important risk managing instrument to offset the periodic dry spells that occasionally occur both in a specific growth season and in certain production years.

Table 3.4 The optimized expected BTNI values (EV(BTNI)) and trigger levels[1] in the three identified plant-growth phases ($X_i$) for Information Strategy 2, replicated 15 times by rerunning the SIMCOM model, under conditions of unlimited and limited water supply on Avalon soil, using 15 years' weather data, 1993

| | UNLIMITED WATER SUPPLY | | | | LIMITED WATER SUPPLY | | | |
|---|---|---|---|---|---|---|---|---|
| REPLICATION | $X_1$ (%) | $X_2$ (%) | $X_3$ (%) | EV(BTNI) (R) | $X_1$ (%) | $X_2$ (%) | $X_3$ (%) | EV(BTNI) (R) |
| 1 | 99 | 96 | 87 | 93 852 | 99 | 100 | 93 | 76 757 |
| 2 | 90 | 99 | 89 | 93 600 | 99 | 100 | 97 | 76 056 |
| 3 | 99 | 96 | 87 | 93 852 | 99 | 100 | 93 | 76 757 |
| 4 | 72 | 97 | 83 | 90 133 | 96 | 100 | 98 | 75 955 |
| 5 | 99 | 100 | 86 | 93 109 | 99 | 100 | 87 | 76 056 |
| 6 | 99 | 94 | 90 | 93 925 | 99 | 100 | 93 | 76 757 |
| 7 | 96 | 96 | 87 | 94 228 | 99 | 100 | 93 | 76 757 |
| 8 | 77 | 97 | 88 | 92 423 | 99 | 100 | 93 | 76 757 |
| 9 | 84 | 99 | 93 | 93 330 | 96 | 100 | 94 | 77 131 |
| 10 | 87 | 99 | 93 | 93 553 | 99 | 100 | 93 | 76 757 |
| 11 | 99 | 99 | 90 | 93 614 | 99 | 100 | 93 | 76 757 |
| 12 | 99 | 97 | 95 | 93 990 | 99 | 100 | 93 | 76 757 |
| 13 | 96 | 99 | 96 | 94 053 | 100 | 100 | 85 | 76 520 |
| Minimum EV(BTNI) (R/ha) | | | | 90 133 | | | | 75 955 |
| Maximum EV(BTNI) (R/ha) | | | | 94 228 | | | | 77 131 |
| Mean EV(BTNI) (R/ha) | | | | 93 358 | | | | 76 598 |
| Standard deviation (R/ha) | | | | 1 035 | | | | 338,7 |
| Coefficient of variation (%) | | | | 1,1 | | | | 0,44 |

1. The percentage to which the soil water content is allowed to be depleted before an irrigation is scheduled.

*If an irrigation in a specific growth stage does not increase the net returns (due to the fact* that soil water is not yet affecting yields) the search procedure will increase the depletion levels in order to prevent the irrigation subroutine from scheduling an irrigation.

## 3.4 RESULTS

### 3.4.1 The effect of better irrigation information on the profitability of irrigation farming in the Winterton area

The effects of better irrigation information on the profitability of irrigation farming in the Winterton area on two soil types that differ in terms of PESW, under conditions of unlimited and limited water supply, are presented in Table 3.5. The amount by which the more sophisticated irrigation information increases the EV(BTNI), compared to the benchmark strategy (the value of information), is also presented in Table 3.5. The profitability of irrigation is presented as the expected total farm before-tax net returns.

Table 3.5 The expected total farm net returns (EV(BTNI)) and the amount by which more sophisticated information strategies increased the EV(BTNI) compared to the benchmark strategy (Strategy 1) on two different soils under conditions of unlimited and limited water supply in the Winterton area for a risk-neutral farmer, 1993

| STRATEGIES | HUTTON SOIL | | AVALON SOIL | |
|---|---|---|---|---|
| | UNLIMITED WATER | LIMITED WATER | UNLIMITED WATER | LIMITED WATER |
| Strategy 1 | | | | |
| EV(BTNI) (R1000's) | 75,0 | 53,6 | 61,2 | 13,3 |
| Information value (R/ha)[(1)] | 0 | 0 | 0 | 0 |
| Strategy 2 | | | | |
| EV(BTNI) (R1000's) | 96,0 | 82,1 | 86,2 | 52,7 |
| Information value (R/ha) | 124 | 168 | 147 | 231 |
| Strategy 3 | | | | |
| EV(BTNI) (R1000's) | 95,2 | 85,2 | 87,2 | 67,7 |
| Information value (R/ha) | 119 | 186 | 153 | 319 |
| Strategy 4 | | | | |
| EV(BTNI) (R1000's) | 96,7 | 86,9 | 87,9 | 69,4 |
| Information value (R/ha) | 128 | 196 | 157 | 330 |
| Strategy 5 | | | | |
| EV(BTNI) (R1000's) | 96,9 | 87,9 | 88,6 | 69,5 |
| Information value (R/ha) | 129 | 202 | 161 | 331 |
| Strategy 6 | | | | |
| EV(BTNI) (R1000's) | 98,1 | 86,4 | 90,6 | 68,2 |
| Information value (R/ha) | 136 | 193 | 173 | 322 |

1. Information value is value per irrigated hectare, obtained by dividing increase in returns by the number of irrigated hectares (170).

The use of better (more sophisticated) information resulted in an increase in the profitability of irrigation, notwithstanding changes in the soil's PESW and the availability of irrigation water. For example, the EV(BTNI) increased from R75 000 for the no-information strategy (Strategy 1) to R98 100 for Strategy 6 (perfect soil, future ET and rain) on the Hutton soil when irrigation water was not limited. Consequently, a risk-neutral irrigation farmer, farming under similar conditions, can pay up to R136/ha to obtain more sophisticated irrigation information.

Diminishing returns on better irrigation information are clearly demonstrated. For example, the checkbook-irrigation strategy (Strategy 2) on the Avalon soil under limited water supply conditions was able to account for 70 % (R231/ha) of the increase in the expected return (R331/ha) generated by the strategy using perfect soil water and future rainfall information (Strategy 5). The information strategy that uses soil-water information with a 15 % random error (Strategy 3) was able to account for 96 % (R319/ha) of the R331/ha increase in expected return generated by using Strategy 5. The future rainfall information, added to the already perfect soil information used in Strategy 4, resulted in a mere 0,5 % increase in expected returns. The increase in the expected net return declined by 2,5 % when future ET information was added to the future rainfall and perfect soil-water information used in Information Strategy 5. Decision makers, farming under similar conditions, would therefore not be willing to pay anything to obtain perfect plant-growth information and, consequently, also ET information, if they already have perfect soil water and future rainfall information.

The inability of Strategy 6 to generate a higher expected net return under limited water supply conditions on both the Hutton and Avalon soils can possibly be the result of triggering irrigation too early in the growth phase when the plant is less sensitive to water stress. This was because ET information used in this research was the amount of water that would have evapotranspired over the next three days if plant growth continued as under dry-land production conditions. As a result, the ET information provided indicates more water evapotranspired than would in actual fact occur if the availability of water was limited and water stress occurred. Obtaining future ET information under limited water supply conditions was difficult, because the level of stress varies between the different information strategies and different plant-growth stages.

Very similar results were obtained under unlimited water supply conditions, except that the highest expected net return was generated by Strategy 6 (most sophisticated irrigation information). Irrigation farmers would be willing to pay between R7/ha and R12/ha more to obtain perfect plant-growth information if they have perfect soil-water information and future rainfall information. The second difference is that the checkbook strategy (Strategy 2) generated a higher expected net return than Strategy 3 (15 % random soil-water information error) on the Hutton soil. The reason is that the 15 % soil-water information error on the Hutton soil with a PESW of 138 mm amounts to an error of 20,7 mm. On this particular soil, the potential error was greater than the potential errors made by Strategy 2, where the soil water content was corrected every week to within 10 mm of the correct soil-water level.

The increase in expected net returns to perfect soil-water information varied between 91 and 99,5 % of the returns generated by the information strategy using future weather information. Even if the soil-water information used had a random error of 15 % of the soils PESW, it would still have been able to account for between 88 and 96 % of the potential gains from using future weather information. The returns to future weather information was relatively low for all the analyzed conditions. However, due to the fact that weather information, as opposed to soil information, is not restricted to a specific farmer's field, the returns on better weather information may be very high even if the per hectare returns are low (Bosch, 1984).

Two critical variables affecting the value of information are the soil's PESW and the availability of irrigation water.

Information strategies using more sophisticated information proved capable of limiting the reduction in the expected net returns when the soil's PESW drops from 138 mm (Hutton) to 77 mm (Avalon). For example, Information Strategy 1 generated an expected return of R75 000 on the Hutton soil (high PESW) compared to the R61 200 on the Avalon soil (low PESW). Information Strategy 6, on the other hand, generated an expected return of R98 100 on the Hutton soil (high PESW) compared to the R90 600 on the Avalon soil (low PESW). There thus was a reduction of R13 800 and R7 500 respectively for Information Strategies 1 and 6 if PESW was lowered from 138 to 77 mm. Consequently, the difference in expected net returns between the more sophisticated information strategies and the benchmark strategy (Strategy 1) increased from R136/ha on the Hutton soil (high PESW) to R173/ha on the Avalon soil (low PESW). A risk-neutral irrigation farmer, farming on a soil with a low PESW, would therefore probably be willing to pay about R37/ha more to obtain better irrigation information than the farmer farming on soils with high PESW. The results imply that better information is a partial substitute for land quality. Better information was able to render the "poor" soil (Avalon) relatively more competitive, in comparison to the "good" soil (Hutton). Information was however not able to totally substitute for higher soil quality.

The importance, and therefore also the value, of more sophisticated irrigation information become more apparent when the availability of irrigation water is limited. The difference between the sophisticated information strategy and the benchmark strategy on the Hutton soil (high PESW) increases by 49 % from R136/ha to R202/ha if the availability of irrigation water is limited. The importance of information on a soil with a low PESW (Avalon) under limited water supply conditions is even more apparent, as demonstrated by the fact that the value of information increased by 91 % from R193/ha to R331/ha. The increases in the value of information are the result of a more than proportional decline in the expected net returns generated by the benchmark strategy compared to the better information strategy. For example, the expected net returns obtained from the benchmark strategy declined by R126/ha from R441/ha to R135/ha when water became limited. By comparison, the expected net returns obtained from Information Strategy 6 under similar production conditions, only declined by R69/ha from R577/ha to R508/ha.

It is again important to note that information is a substitute for water. Better information was able to reduce the adverse effects that limited water had on the profitability of irrigation farming.

### 3.4.2 The effect of better irrigation information on yield and water use

The expected per hectare maize yields and the associated irrigation water used by the identified information strategies which were maximized by the SIMCOM model on two soil types under conditions of unlimited and limited water supply are presented in Table 3.6.

Better irrigation information had a relatively small effect on the expected yields generated by all four of the alternatives analyzed. The lowest maize yields realized on the Hutton soil under unlimited water supply conditions were only 54 kg lower than the 9 726 kg/ha realized by the better information strategy (Strategy 6). Under limited water supply conditions the difference was only 470 kg. In contrast, more sophisticated irrigation-information strategies used substantially less irrigation to obtain nearly the same yields. For example, Information Strategy 6 used 153 mm/ha and 110 mm/ha less water than the no-information strategy (Strategy 1) on the Hutton (high PESW) and the Avalon soil (low PESW) respectively.

Interesting is the fact that the average amount of irrigation water applied by the more sophisticated irrigation-information strategies proved to be substantially less than the 150 mm/ha that are available under limited water supply conditions. For example, Irrigation-Information Strategy 6 on the Hutton soil with limited water applied only an average of 115 mm of the 150 mm that are available. The search procedure adjusted the trigger levels in such a way that the farmer had enough irrigation water to apply in very dry weather years. Consequently, it proved better (more economic) to have unused irrigation water reserves in some years so that enough irrigation water is available in weather years when big yield losses occur as a result of severe water stress.

Table 3.6 The expected maize yield (per hectare) and the expected irrigation water applied (mm/ha) by the identified information strategies which were optimized by the SIMCOM model, on two soil types under conditions of unlimited and limited water supply in the Winterton area with a long-term average rainfall of 674 mm/year for a risk-neutral farmer, 1993

| STRATEGIES | HUTTON SOIL (high PESW) | | AVALON SOIL (low PESW) | |
|---|---|---|---|---|
| | UNLIMITED WATER | LIMITED WATER | UNLIMITED WATER | LIMITED WATER |
| Strategy 1 | | | | |
| Yield (kg/ha) | 9 672 | 9 021 | 9 464 | 8 416 |
| Water (mm/ha) | 306 | 148 | 306 | 148 |
| Strategy 2 | | | | |
| Yield (kg/ha) | 9 693 | 9 416 | 9 716 | 9 003 |
| Water (mm/ha) | 153 | 129 | 240 | 144 |
| Strategy 3 | | | | |
| Yield (kg/ha) | 9 710 | 9 461 | 9 645 | 9 231 |
| Water (mm/ha) | 168 | 128 | 197 | 146 |
| Strategy 4 | | | | |
| Yield (kg/ha) | 9 680 | 9 470 | 9 673 | 9 252 |
| Water (mm/ha) | 141 | 117 | 206 | 143 |
| Strategy 5 | | | | |
| Yield (kg/ha) | 9 708 | 9 491 | 9 669 | 9 247 |
| Water (mm/ha) | 153 | 118 | 197 | 135 |
| Strategy 6 | | | | |
| Yield (kg/ha) | 9 726 | 9 458 | 9 695 | 9 238 |
| Water (mm/ha) | 153 | 115 | 196 | 145 |

### 3.4.3 The value of information if yield and output prices are perfectly negatively correlated

The effects of perfectly negatively correlated yield and product prices on the value of perfect soil-water information on the Hutton and Avalon soils under conditions of unlimited and limited water supply are compared in Table 3.7 to the value of information determined under similar production conditions by assuming no correlation between yield and product prices.

The value of perfect soil-water information for a risk-neutral decision maker with unlimited water increased by R6/ha (5 %) and R8/ha (5 %) on the Hutton and Avalon soils respectively, if yield and product prices were perfectly negatively correlated. The increase in expected net returns was slightly higher on the Hutton (high PESW) and Avalon (low PESW) soils with limited water, where the increases were R22/ha (11 %) and R18/ha (5 %), respectively. The slight increase in the value of information for risk-neutral decision makers may be the result of the particular price-yield vector used.

Slightly different results might be obtained if another price-yield vector were generated with a different seed value.

Table 3.7 The effect of perfectly negatively correlated yield and product prices on the value of perfect soil-water information (Strategy 4), on two different soil types under conditions of unlimited and limited water supply in the Winterton area for a risk-neutral farmer, 1993

| STRATEGY 4 | HUTTON SOIL (high PESW) | | AVALON SOIL (low PESW) | |
|---|---|---|---|---|
| | UNLIMITED WATER (R/ha) | LIMITED WATER (R/ha) | UNLIMITED WATER (R/ha) | LIMITED WATER (R/ha) |
| Correlation = 0 | 128 | 196 | 157 | 330 |
| Correlation =-1 | 134 | 218 | 165 | 348 |

It seems, however, that the value of information for risk-neutral decision makers is not greatly affected by the assumption that yield and product prices are not correlated.

## 3.5 CONCLUSIONS

Irrigation, economic and crop-growth simulation models, as well as an efficient search optimizer were successfully linked and used to evaluate the role of information for an irrigated crop system under conditions of unlimited and limited water supply.

The use of more sophisticated irrigation information improved the irrigator's ability to adjust the timing of irrigation. Consequently, more sophisticated irrigation information increased expected net returns due to the attainment of near maximum yield with savings on the amount of irrigation water used.

The increase in expected net returns or the value of information was sensitive to changes in the soil's PESW and the availability of irrigation water. Risk-neutral farmers farming on soils with lower PESW can pay up to R37/ha more than the R136/ha paid by farmers farming on soils with higher PESW, to obtain more sophisticated irrigation information.

If limited amounts of irrigation water are available, the value of information on the two analyzed soil types increased by 49 and 91 % from R136 ha to R202/ha (Hutton soil) and from R173 ha to R331/ha (Avalon soil), respectively.

The results prove that information is a substitute for land quality and water availability. As population pressure increases on the available land and water resources in South Africa and elsewhere, the importance of information may increase.

Site specific soil information could account for between 97 and 99 % of the returns generated by information strategies using future weather information. Because soil information accounts for a large fraction of better information-producing technology and because soil information is specific to a farmer and field, irrigation farmers would probably rather invest in better soil-water information. Research to produce better weather predicting technology might also prove useful, because weather information can be applied to a wider area and might yield a higher return over the cost of producing it than soil-water information when applied to a larger area.

The value of perfect soil-water information for a risk-neutral decision maker under conditions of unlimited and limited water supply increases by between 5 and 11 % if yields and product prices are perfectly negatively correlated. The value of information is not greatly affected by the assumption that yield and product prices are not correlated.

## 3.6 IMPLICATIONS FOR FURTHER RESEARCH

The SIMCOM model can be applied to various decision-making problems on irrigation farms. For example, the SIMCOM model can be used to evaluate the effect of different pumping restrictions and electricity-management strategies on the economic profitability of irrigation farming. It can also be used to determine the optimum planting dates, plant populations and other management practices.

The value of irrigation information should also be determined for decision makers with non-neutral risk preferences. This would firstly require the elicitation of absolute risk-aversion coefficients for irrigation farmers in the Winterton area, and secondly, the changing of the SIMCOM model to optimize expected utility instead of expected net returns.

The methodology which has been developed and coded into the SIMCOM model, might be used to assist irrigation farmers with real-time irrigation-scheduling decisions. This might be accomplished by adjusting the SIMCOM model's search procedure to search in a sequential fashion, only concentrating on the time span over which the decision is to be made. For example, the decision to initiate an irrigation can be evaluated by searching over realistic alternatives, where everything that has happened up to the time the decision is made, is taken as fixed, and everything in the future as the best guess or the average of historical events that represent the same period. This process can be repeated each time an irrigation decision is made until harvesting. It would be very interesting to compare the value of information determined using the above-mentioned procedure to the results obtained in this research.

An extension of this research would be to determine to what extent the frequency and amount of rainfall affect the value of information. Because of the relatively high rainfall in the research area, errors made by using less sophisticated irrigation were frequently corrected when rain refilled the soil profile. A preliminary hypothesis would be that the value of irrigation information would increase as the frequency and amount of rainfall decrease. The effect of future ET information, obtained under water stress conditions, on the profitability of irrigation farming when water is limited, also requires further research.

The potential is there to improve the accuracy with which the SIMCOM model estimated the value of better irrigation information even further, if the accuracy of crop-growth simulation models could be improved, especially under conditions of limited water supply (deficit irrigation).

Botes (1990) investigated the opportunity cost of saved water at farm level. However the opportunity cost of water on regional level should be further investigated to determine the benefits of water saved at farm level for industrial and other down stream users.

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# CHAPTER 4

# ELICITATION OF RISK PREFERENCES FOR IRRIGATION FARMERS IN THE WINTERTON AREA: WEALTH RISK VERSUS ANNUAL INCOME RISK

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## 4.1 INTRODUCTION

Irrigation farmers in Western Natal are facing risky decisions, such as whether to use and/or implement more sophisticated irrigation-scheduling strategies, build water storage facilities and invest in new irrigation equipment, which will significantly affect their prosperity. Analyses of such decisions must first account for the risk preference of the farmer or his willingness to assume risk. Secondly, analysis dealing with wealth risks such as irrigation investment, should examine the effects of uncertainty on the dispersion of wealth, rather than on annual income (McCarl and Musser, 1985). Stochastic dominance with respect to a function (SDWRF) has become a very popular method for analyzing risky decisions, because it accounts for preferences by placing lower and upper bounds on the Arrow-Pratt absolute risk-aversion function (King and Robison, 1981). Appropriate Arrow-Pratt coefficients can either be obtained from coefficients elicited in other studies, or by eliciting the coefficients oneself.

Risk preferences over uncertain wealth (potential income generated by an investment over several years) have not yet been locally elicited. In addition, risk-elicitation studies (*e.g.*, Meiring and Oosthuizen, 1993; Lombard and Kassier, 1990; Tauer, 1986; Cochran, Robison and Lodwick, 1985; Wilson and Eidman, 1983) have only elicited risk preferences on an annual income basis. Consequently little is known about how risk attitudes change when wealth instead of annual income is at risk. There is also a lack of empirical evidence to guide the selection of risk intervals for eliciting risk preferences when long-term instead of annual income is at stake.

The main objective of this research was to determine whether attitudes toward wealth risk were significantly different from attitudes towards annual income risk. In relation to this objective the following null hypothesis was tested: Ho: r(w) = cr(x), namely that attitudes towards wealth risk, r(w), are not significantly different from risk attitudes towards annual income risk, cr(x), where c is a rescaling factor that accounts for the differences in the wealth and income scales (Cochran and Raskin, 1987).

Other objectives were the following:

1) To obtain risk-aversion coefficients (RACs) for use in farm level analyses concerning annual income and wealth risk.
2) To determine whether decision makers will have decreasing absolute risk-aversion as the level of annual income and wealth increases. In relation to this objective the following null hypothesis was tested: decision makers will have a constant absolute risk-aversion function as the level of annual income/wealth increases.
3) To test whether the consistency with which risk preferences are measured differs when the level of the outcome measure (income or wealth) increases, or when wealth instead of annual income is used as a performance measure.

## 4.2 CONCEPTUAL MODEL

The expected utility maximization theory developed by Von Neumann-Morgenstern (1947) provides a set of tools required for the analysis of economic behaviour under conditions of risk and uncertainty. Von Neumann and Morgenstern (1947) showed that if six axioms are satisfied, the decision makers' preferences can be represented with a utility function, U(x) (Hey, 1979). This utility function can be used for predicting the choices that the individual will make when confronted with sets of risky alternatives.

The shape of the utility function implies either risk-neutrality, risk-aversion or a risk-seeking attitude. If the utility function is concave ($U''(x) < 0$), the decision maker is risk averse. The decision maker will thus prefer an action with perfectly certain returns to another action with equal, but uncertain expected returns (Robison, Barry, Kliebenstein, and Patrick, 1984). A linear utility function ($U''(x) = 0$) implies risk neutrality; on the other hand, a convex function ($U''(x) > 0$) implies a risk-seeking attitude.

Although risk attitudes can be determined by looking at the sign of the utility functions' second derivative, it is important to remember that an infinite number of such utility functions can be generated, each of which will preserve the ordering of a decision makers' preference over risky alternatives. The magnitude of the second derivative cannot be used for interpersonal comparisons of risk aversion; the reason is that an individual's utility function is only unique up to a positive linear transformation. The risk preference indicator, U"(x), can be arbitrarily varied by multiplying the utility function by any positive number (Hey, 1979).

To overcome this problem, Pratt (1964) and Arrow (1971) have taken the rate of change in the slope (second derivative) of the utility function and normalized this value by the slope (first derivative) of the utility function. The result is the Arrow-Pratt measure of absolute risk aversion, denoted by r(x):

$$r(x) \quad = \quad -U''(x) \;/\; U'(x) \tag{1}$$

where x is the appropriate performance indicator (outcome variable).

According to Hey (1979) the Arrow-Pratt measure of absolute risk aversion, r(x) has the following properties:

1) If $r(x) < 0$, $=0$ or $>0$ then the individual displays risk-seeking, risk-neutral or risk-averse preferences, respectively.
2) r(x) is larger for a more risk-averse individual than for a less risk-averse individual.
3) r(x) is unaffected by an arbitrary linear transformation of the utility function.

Raskin and Cochran (1986:204), however, point out that the invariance property (point 3) of the Arrow-Pratt absolute risk-aversion coefficient only applies with respect to transformations of U and not with respect to arbitrary rescaling of the outcome variable, x. The Arrow-Pratt can be interpreted as the negative of the percentage change in marginal utility per unit of outcome space; therefore the value of the coefficient is associated with a reciprocal of the unit with which the outcome space was measured (Raskin and Cochran, 1986:205). For this reason, Arrow-Pratt coefficients elicited over an outcome space measured in one unit/currency must be converted by the appropriate factor before it can be applied over outcomes measured in another unit/currency (Raskin and Cochran, 1986: 206).

Two theorems were introduced by Raskin and Cochran (1986) to guide the rescaling of the Arrow-Pratt coefficients, assuming that utility levels remain constant.

THEOREM 1. Let $r(x) = -U''(x)/U'(x)$. Define a transformation of scale on x such that $W = x/c$, where c is a constant. Then $r(w) = cr(x)$.

THEOREM 2. If $v = x + c$, where c is a constant, then $r(v) = r(x)$. McCarl (1987:228) demonstrated that the RAC at income level x is not always equal to the RAC at wealth level $v = x + c$. Later Cochran and Raskin (1987:231) altered the theorem to especially recognize the wealth/incremental distinction. They present the following equation:

$$r_W(x + c) = r_{i/c}(x) \qquad (2)$$

where $r_W$ is risk aversion to wealth and $r_{i/c}$ is the risk aversion to incremental returns given previous wealth level c. According to this theorem, the willingness to deviate from, for example, a \$110 000 wealth level will be equivalent to the willingness to deviate from a \$10 000 incremental return (annual income) level given wealth is already \$100 000, if the decision maker can mentally account whether a wealth dollar or an annual income dollar is at stake.

### 4.2.1 Measurement of risk attitudes

There are four principal approaches to estimating risk preferences: (1) direct elicitation of utility functions, (2) experimental methods, (3) observed economic behaviour, and (4) interval measurement of risk aversion.

Several review articles provide excellent summaries of the extensive literature on farmers' risk attitudes (Hazel, 1982; Young, 1979; Young, Lin, Robison and Selley, 1979; Anderson, Dillon and Hardaker, 1977). Because the interval approach is used in this research to elicit the absolute RAC for irrigating farmers, this approach (also called stochastic dominance with respect to a function or SDWRF) is discussed in more detail.

#### 4.2.1.1 The risk interval approach

Due to the measurement errors inherent in eliciting and deriving single-value utility functions, King and Robison (1981) developed an operational approach for eliciting risk preferences. Rather than representing preferences exactly, the interval approach establishes lower and upper bounds on individuals' absolute risk-aversion functions. By defining an interval, researchers can allow for the possibility of measurement error or instability of preferences across decision settings and time (Cochran, 1986). The wider the interval, the less precise the preference representation (larger probability of a Type II error, including risk preferences that should not have been included). In this case, the analysis does not detect a preference between the two alternatives, while actually the one is preferred to the other. The narrower the interval, the more precise is the preference representation (larger probability of a Type I error, excluding risk preferences that should not have been excluded). In this case, an inaccurate ranking of the alternative strategies has occurred. The width of the preference interval is thus related to the likelihood of Type I and Type II errors. King and Robison (1981) found that by narrowing the preference interval the incidence of Type II errors was lowered from 91 to 9 % while the incidence of Type I errors increased from 2 to 28 %.

The interval approach draws heavily on the theoretical developments of stochastic dominance (Meyer 1977, 1975). Meyer showed that a boundary utility function, k(x), can be found in risk-aversion space that divides agents into subsets, namely those agents who are more risk averse than k(x) and those who are less risk averse. A utility function of the form $k(x) = -e^{-r(x)x}$ with an absolute risk-aversion function of $r(x) = -U''(x)/U'(x)$ can be estimated so that one cumulative distribution function F(x) is preferred to another G(x) by all decision makers who are more risk averse than r(x). If G(x) is preferred to F(x) one knows that those individuals are less risk averse than r(x) (Wilson, 1982).

King and Robison (1981) assume that distributions F(x) and G(x) are defined over a narrow range of outcome levels and that the decision makers' absolute risk-aversion function can be approximated by a constant risk-aversion measure over a narrow range of output levels. The constant absolute risk-aversion measure can be calculated such that the expected utilities for the two distributions, F(x) and G(x), are approximately equal. If the decision maker prefers F(x), it implies that the constant risk-aversion measure, ß, is greater than or equal to the minimum value of the absolute risk-aversion function associated with k(x). Preference for G(x), on the other hand, implies that ß is less than or equal to the maximum value of the absolute risk-aversion function associated with k(x) (King and Robison, 1981).

By routing an individual through a series of questions involving the selection of the preferred of two distributions, it is possible to place lower and upper bounds on an individual's absolute RAC. The INTID program, developed by King and Robison (1981), generates the sample probability distributions which serve as the basis for the choices used to reveal the decision makers' preferences and identifies boundary intervals for as many distributions as possible.

Two concerns have arisen in respect of the implementation of interval approach. One is the difficulty of establishing an appropriate scale for measuring absolute risk aversion (King, 1986); in other words, of defining of the preference interval (Cochran, 1986). The other has been the scaling of the outcome variables (*e.g.*, enterprise, whole farm or wealth).

Most risk-elicitation studies adjust and use preference intervals from other studies. King and Robison (1981) first suggested a set of 16 reference levels on the measurement scale ranging from -0,001 to 0,1. Wilson and Eidman (1983) used a small part of the suggested scale (-0,0005 to 0,001) to elicit risk preferences of swine producers in the USA, for annual before-tax net income (BTNI) levels ranging from $16 500 to $55 000. They found that 69 % of swine producers had preferences ranging from -0,0002 to 0,0003. Eleven per cent of the farmers fell in an interval ranging to extreme risk seeking (-0,0001; -∞), and, at the other end of the scale, 20 % of the farmers fell in an interval ranging to extreme risk aversion (0,0002; +∞).

The risk preference measurement scale used by Wilson and Eidman (1983) has a high Type I error probability. This was proven by the fact that Wilson and Eidman (1985), when selecting risk intervals for the efficiency analysis of the swine production industry, chose to widen their original measurement scale to accommodate more risk-seeking and risk-averse decision makers. The boundary intervals, -0,0002 to -0,001; -0,001 to -0,04; 0,0002 to 0,001 and 0,001 to 0,03 were included in their analysis to accommodate the more risk-seeking and more risk-averse decision makers.

Tauer (1986), when selecting a measurement scale for eliciting annual income risk preferences of New York dairy farmers, adjusted the scale used by Wilson and Eidman (1983), so as to accommodate more risk-averse decision makers, but retained more or less the same intervals on the risk-seeking end of the measurement scale. The results revealed that only two of the 72 farmers could not be bounded by the adjusted risk-averse end of the measurement scale. There were, however, still 12 risk-seeking farmers (17 %) on the other end of the scale who could not be bounded by the risk-seeking intervals selected. Tauer (1986) concluded that future surveys might seek to adjust the risk-seeking end of the measurement scale to include an extreme risk-seeking interval.

### 4.2.2 Conclusions from the literature

The specification of a measurement scale is the first step in the implementation of the interval approach. Special attention needs to be given to the definition of the preference interval and the scaling of the outcome variables.

A large number of different preference intervals (risk intervals) have been used (see Cochran, 1986) to represent risk preferences. Clearly the measurement scales used in the USA for the elicitation of attitudes toward annual income risk have improved in terms of the trade-offs between the probabilities of Type I and Type II errors. The risk intervals used by Tauer (1986) can be further improved by including an extreme risk-seeking interval, as was done by Meiring and Oosthuizen (1993).

A measurement scale for the elicitation of SA farmers' attitudes toward annual income risk can be obtained by rescaling the measurement scales used in the USA. Raskin and Cochran (1986) describe a procedure to approximate risk intervals, maintaining similar attitudes, when the outcome variable has changed. When the currency value associated with absolute risk-aversion coefficient (RAC) is changed from dollar ($) to rand (R), the R/$ exchange rate can be used as a rescaling factor. Meiring and Oosthuizen (1993) use a R/$ exchange rate of R3-to-$1.

## 4.3 *MATERIAL AND METHODS*

### 4.3.1 Irrigation farms in the Winterton area

A comparative study of attitudes toward wealth risk versus attitudes toward annual income risk was carried out involving 53 farmers in the Winterton area. Sources of risk as well as the ways in which farmers adjust their farming practices to account for variability were established. In addition, socioeconomic information, including aspects such as the farmers' financial situation, biographical data and the type of farming arrangement, as well as information concerning the farming operation and including aspects such as enterprise selection, cultivated hectares and irrigation equipment, was obtained.

The ages of the 53 respondents in the Winterton area vary between 24 and 71 years. The average farm size is 764 ha, of which 631 ha is owned by the farmer himself and 133 ha is leased. The number of hectares under irrigation varies between 10 and 320 ha. Farmers have a variety of crop and livestock enterprises. Land used for dry-land crop production varies between 0 and 730 ha, while land used for grazing varies between 0 and 1500 ha. Irrigation is used on about 47 % of the cultivated land or 16 % of the total farm size.

Forty-four per cent of the irrigation farmers supplement their income with money derived from non-farming activities. The gross annual income varies between R20 000 and R3 000 000. However, 78 % of the farmers receive a gross annual income of less than

R1 000 000, 55 % of whom receive less than R500 000 annually. Thirty-one (60 %) of the 53 farmers have a total net worth of less than one million rand.

### 4.3.2 Annual income measurement scale

The first step was to adjust the measurement scale used by Tauer (1986). The intervals at the risk-seeking end of the measurement scale were widened. The measurement scale was then rescaled to elicit annual income risk preferences for SA farmers. This was done by dividing the annual income (USA) measurement scale by the exchange rate. The exchange rate ratio used by Meiring and Oosthuizen (1993) was kept unchanged. The annual income and wealth-measurement scales, used to elicit risk preferences in respect of annual income and wealth risk are presented in Table 4.1.

Table 4.1 Annual income and wealth-measurement scales used in the Winterton area to elicit risk preferences towards annual income and wealth risk, 1993

| RISK GROUP | ANNUAL INCOME MEASUREMENT SCALE | | | WEALTH-MEASUREMENT SCALE | | |
|---|---|---|---|---|---|---|
| | Lower Bound | | Upper Bound | Lower Bound | | Upper Bound |
| 1 | -∞ | to | -0,00017 | -∞ | to | -0,000017 |
| 2 | -0,00030 | to | -0,00003 | -0,000030 | to | -0,000003 |
| 3 | -0,00017 | to | 0,00000 | -0,000017 | to | 0,000000 |
| 4 | -0,00003 | to | 0,00003 | -0,000003 | to | 0,000003 |
| 5 | 0,00000 | to | 0,00010 | 0,000000 | to | 0,000010 |
| 6 | 0,00003 | to | 0,00030 | 0,000003 | to | 0,000030 |
| 7 | 0,00010 | to | 0,00170 | 0,000010 | to | 0,000170 |
| 8 | 0,00030 | to | +∞ | 0,000030 | to | +∞ |

The annual income measurement scales consisted of eight risk groups, each with an upper and a lower bound. Risk group 2 on the annual income scale, for example, is an interval with a lower RAC of -0,0003 and an upper RAC of -0,00003.

### 4.3.3 Annual income and wealth performance measures

In order to evaluate annual income versus wealth risk, it is important to define annual income and wealth correctly for the decision makers. The emphasis therefore was on selecting performance measures that were well defined and familiar to irrigation farmers in Winterton.

The performance measure selected for the elicitation of annual income risk preferences is before-tax net farm income (BTNI). BTNI is calculated by subtracting all fixed and variable costs incurred over the particular year from the total annual gross income. In other words, the outcome values presented in the distributions were money available over the next year for paying principal instalments on all short-term, intermediate, and long-term loans, family living expenses, expansion of the farm, new machinery and income tax.

From the farmers' financial data, and with the assistance of a local chartered accountant, low, medium and high BTNI levels of R0 (4500), R60 000 (9000) and R120 000 (18400) were identified for farmers in the area. The values in parentheses are the standard deviations (STDs) used in the INTID elicitation program that generates choice distributions (King and Robison, 1981). The STDs were calculated as 15 % of the selected BTNI values, because they were big enough to reflect some variations in BTNI levels experienced by irrigation farmers, while still close enough to the 10 % STD used by Tauer (1986). The standard deviation should not be too large, because the elicitation procedure assumes that absolute risk aversion remains constant over the range of outcomes reflected within a distribution that is compared to other distributions by the respondent (King and Robison, 1981).

Wealth is expressed as the net present value (NPV) of returns from an irrigation investment over 15 years using Equation 1 (Bosch, Taylor and Ross, 1988).

$$NPV = -C_0 + ATNI + D + S \qquad (3)$$

Where, $C_0$ refers to the installed purchase cost of the irrigation system, ATNI is the present value of the after-tax net returns generated from the irrigation system, D is the present value of the depreciation claimed for income tax, and S is the after-tax present value of the salvage value of the irrigation system.

Wealth was explained on the NPV basis, because all the irrigation farmers were faced with a similar decision in the past. For example, NPV calculated by using Equation 3 was explained to the decision makers as the total amount of money to be received over the next 15 years, after paying for all the costs associated with both production and the irrigation system itself (including taxes) and collecting all possible tax savings from the system as well as the ending salvage value. From this money, however, the following still has to be paid: the irrigation enterprise's share of the existing loans on machinery and land, living expenses for the next 15 years and expansion of the farming operation.

The 15-year NPV calculated by Meiring and Oosthuizen (1991) for irrigation investment decisions was used as a benchmark for selecting realistic levels of return on irrigation investment decisions. Low, medium and high wealth levels of R250 000 (37500), R600 000 (90000) and R950 000 (142500) were selected. The STD in parentheses, were also calculated as 15 % of the 15-year NPV levels selected.

#### 4.3.4 Wealth-measurement scale

The annual income measurement scale could now be rescaled to a wealth-based measurement scale according to the theorems presented by Raskin and Cochran (1986:206). A rescaling factor of 10 was used, because the medium annual income and wealth levels differ by a factor of 10 (*i.e.*, R60 000 BTNI versus R600 000 NPV). The absolute RACs for eliciting wealth-risk preferences were obtained by dividing the annual income RACs by 10. This resulted in one wealth-measurement scale for all three outcome levels as shown in Table 4.1.

#### 4.3.5 Questionnaire

Twenty distributions with six values each, rounded off to the nearest R100, were generated for each of the selected income/wealth levels according to the specified measurement scales.

With the INTID program pairs of distributions were generated having the specified standard deviation, and which were divided by the indicated boundary interval, k(x); corresponding to one of the intervals in Table 4.1. In other words, if the two distributions were F and G, with F more risky than G and with the boundary interval = 0,000 to 0,0001, preference for F indicated risk aversion greater than 0,000 while preference for G indicated risk aversion less than 0,0001. By asking the decision makers to select from such pairs of distributions, it was possible to determine the upper and lower bounds of the decision maker's absolute risk-aversion function. Risk preferences for each of the selected income levels were obtained by repeating this process.

The procedure of Meiring and Oosthuizen (1993) was used to test whether the decision makers were consistent in their choices. This was done as follows: Annual income risk preferences around each of the three BTNI levels were elicited by constructing two separate questionnaires. The two questionnaires were then linked so that risk preferences around the low BTNI level could be elicited twice before going on to the medium BTNI level. With the three levels of income and the duplication at each level, the annual income elicitation questionnaire consisted of 42 questions of which decision makers answered only 18. The same procedure was followed in constructing a wealth elicitation questionnaire. Finally the income and wealth questionnaires were combined in one questionnaire. However, the annual income and wealth questionnaires were still separate units with their own introductions and practice example, as well as question numbers from 1 to 42.

The *questionnaire consisted of two main parts. Each part was preceded by an* introduction. The introduction was developed to cover the main points of the Stanford/SRI assessment protocol (Morgan and Henrion, 1990), which was developed for elicitation of subjective probabilities, but which is also appropriate for risk elicitation. The decision makers were first informed about the purpose of the risk elicitation and how the results would be used. Care was taken not to give rise to any motivational bias by stressing that the study would be used for research purposes only and that there were no right or wrong answers. The structure of the questionnaire was then explained along with the uncertainties associated with the BTNI and NPV variables. This was done by defining the properties of the two outcome variables in terms of how they were computed and the sources of risk to which they were subjected. The introduction was followed by a short exercise. Similarly, the wealth elicitation part of the questionnaire consisted of the introduction, a short practice question and the elicitation section of the questionnaire.

### 4.3.6 Selection criteria

Different selection criteria were used to select the elicited risk preferences that were used in the analyses. Only decision makers that were consistent in their risk preferences were included in the analyses. A decision maker was regarded as consistent if his second round elicitation was within two intervals, on either side, of his original choice at the different outcome levels. *The two-interval-on-each-side decision rule was used, because risk* preferences can be separated by one complete risk interval and still be consistent (Tauer, 1986). For example, a decision maker was still considered to be consistent even if he was for example, placed in interval 6 (RAC ranging from 0,00003 to 0,0003, Table 4.1) during the first round elicitation and in interval 4 (-0,0003 to 0,00003) when the elicitation was replicated. The reason is that the RAC value of 0,00003 is common in intervals 4, 5 and 6.

Only decision makers that were consistent on either all three of the annual income levels or on all three of the wealth levels were included in the analyses to determine whether RACs remain constant over increasing/decreasing levels of income/wealth. As a result, decision makers were dropped from the annual income elicitations if they failed one or more consistency tests in the annual income elicitations. However, the decision maker could still be included in the wealth elicitations if he was consistent in all three wealth risk elicitations. The probability of passing this decision criterion for all three of either the income or wealth levels by randomly selecting answers is only 0,15.

Thirty of the 53 farmers (57 %) interviewed, were consistent on all three annual income elicitations. Similarly, 33 farmers (62 %) were consistent on all three wealth elicitations. The number of consistent decision makers on both the annual income and wealth elicitations was in accord with results obtained by Tauer (1986) and Meiring and Oosthuizen (1993).

Where the differences between RACs elicited on an annual income basis were compared to RACs elicited on a wealth basis, only decision makers that were consistent on all six of the annual income and wealth levels were included. The probability of passing all six consistency tests by randomly selected answers is 0,02. Only 20 of the farmers (38 %) were consistent on all six annual income and wealth levels.

Risk preferences were first tested to determine whether the obtained consistency results might not be the result of selecting the correct distributions randomly. The test statistic used, assumes a normal approximation of the binomial distribution, and relates the number of consistent decision makers with the probabilities of passing the two-interval-on-each-side decision rule for all three of the annual income and/or wealth levels (Tauer, 1986). The test, in essence tested whether the actual pass rate obtained in the elicitations was significantly different from what it would be if it were assumed that decision makers selected distributions randomly. A two-tailed standard normal (z) distribution at a 99 % confidence level ($\alpha = 0{,}01$) with critical z-values of -2,575 and 2,575 was used to compare the actual passing rates against one obtained with random selections. Z-values of 8,62 and 9,79 were calculated by using the actual annual income and wealth pass rates, respectively. A z-value of 17,62 was obtained when only the 20 consistent decision makers were used. All three of the calculated z-values are highly significant when compared to critical z-values at a 99 % confidence level. Risk preferences obtained in this research could therefore be used in further analyses, because preferences were not obtained from randomly selected preference distributions.

### 4.3.7 Testing of the hypotheses

Risk preferences, as elicited in the second elicitation (replication of the questionnaire), were taken as the best representation of the actual risk attitudes of farmers in the

Winterton area. However, the Wilcoxon Test Statistics, using the first round risk elicitations, were also calculated and used as supportive statistics to determine whether decision makers have decreasing absolute risk aversion as the level of annual income and wealth increases. If the test statistics obtained from both the first and second round elicitations were to reject the hypotheses, all other RACs between the first and second round elicitations would result in the rejection of the hypotheses. The reason is that the *first and second round elicitations formed the two outer perimeters of the interval over* which RACs varied.

The Wilcoxon rank-sum test for two matched samples was used to test the null hypothesis, that attitudes towards wealth risk are not different from risk attitudes towards annual income. The Wilcoxon Test is the nonparametric analog of the parametric paired t-test. Tauer (1986) used the Wilcoxon Test because it uses the magnitudes of the differences as well as the sign in testing for the equality between the means of the two populations (Hays and Winkler, 1970; Zar, 1984).

The SOLO computer package (Hintze, 1991) was used to compare the different samples. The Wilcoxon Test produced a test statistic z-value, along with its probability value, p-value. It can be concluded that the differences between the means of the two populations are significantly different at $p < 0,05$. It was decided to test the null hypothesis at a 95 % ($\alpha = 0,05$) confidence level because of the higher probability of a Type II error (*i.e.*, of concluding that there is no difference between income and wealth risk attitudes when in fact there is) when nonparametric tests are used (Triola, 1980). In other words, there would be sufficient ground for rejecting the null hypothesis, namely that the means are equal, if the probability of obtaining the z-value, calculated by the Wilcoxon Test, is less than 0,05. If the probability (p) of obtaining the z-value is less than 0,001 *it is assumed that there is a highly significant difference between the means of the* two populations. The hypothesis that decision makers will have decreasing absolute risk aversion over increasing levels of income/wealth was also tested by the Wilcoxon Test.

## 4.4 RESULTS AND DISCUSSION OF THE RESULTS

### 4.4.1 Annual income versus wealth-risk preferences

The total number of consistent second round elicitations in each of the identified absolute risk-aversion interval groups, for both the BTNI and NPV outcome variables, is presented in Table 4.2. The risk preferences elicited on all three of the income and wealth levels, for the 20 irrigation farmers, add up to 60 preferences, respectively. The frequency data presented in Table 4.2 were used to test whether risk preferences towards wealth risk are significantly different from attitudes towards annual income.

Table 4.2 Total number of consistent second round elicitations (n=60) at each of the identified risk intervals for both the BTNI and NPV performance measures, 1993

| PERFORMANCE MEASURES | ABSOLUTE RISK-AVERSION INTERVAL GROUPS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| BTNI | 0 | 3 | 23 | 13 | 11 | 5 | 5 | 0 |
| NPV | 1 | 3 | 12 | 15 | 16 | 6 | 4 | 3 |

The Wilcoxon Test using the total number of consistent second round elicitations, produced a p-value of 0,00007 indicating that there was a highly significant difference between the responses obtained on a BTNI basis and those obtained on a NPV basis. The test was repeated on the frequency distributions obtained from the first round elicitations. The first choice preferences produced a p-value of 0, confirming the results obtained from the second round elicitations. In both cases z-values with positive signs were obtained, indicating that RACs moved towards the positive (risk averse) end of the measurement scale when wealth was at stake. The statistical tests are supported by the fact that on annual income level most of the decision makers were placed in risk intervals 3, 4, 5 and 6. However, at the NPV elicitations the most decision makers shifted into risk intervals 4, 5, 6, 7 and 8.

The risk attitude of decision makers towards wealth risk differs significantly from their attitudes towards annual income. Given the fact that RACs were rescaled from the annual income measurement scale, decision makers became more risk averse if wealth instead of annual income is at stake. Wealth losses may take years to recoup, whereas annual income losses may be recouped in the following year(s).

A decision maker can be categorized in different income and wealth intervals, firstly, because of differences in his attitude towards annual income and wealth risk, secondly because of changes in the measurement scale (rescaling factor), and finally, because of an incorrect interpretation of wealth. In this research care was taken to account for the influence of the rescaling factor. However, additional care can be taken by better controlling for a uniform rescaling factor. This will further ensure that incorrect rescaling is not responsible for incorrect categorization of risk preferences.

### 4.4.2 Absolute risk aversion as income/wealth increases

The nature of risk preferences towards annual income and wealth risk for irrigation farmers in the Winterton area is presented in Table 4.3. Table 4.3 is a frequency table with the number of decision makers categorized, according to their second round choices, in each of the risk-aversion intervals for the three selected annual income and wealth levels. For example, 17 decision makers were categorized in risk group 3 (RACs between -0,00017 and 0) around the BTNI level 1.

Table 4.3 Number of irrigation farmers in the Winterton area categorized according to their RACs elicited in the second round at the three selected annual income and wealth levels, 1993

| PERFORMANCE MEASURE | ABSOLUTE RISK-AVERSION INTERVAL GROUPS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| ANNUAL INCOME (R) | | | | | | | | |
| 0 | 2 | 1 | 17 | 4 | 2 | 4 | 0 | 0 |
| 60 000 | 2 | 2 | 11 | 4 | 4 | 2 | 5 | 0 |
| 120 000 | 1 | 2 | 8 | 9 | 6 | 1 | 2 | 1 |
| Total number | 5 | 5 | 36 | 17 | 12 | 7 | 7 | 1 |
| % | 5,5 | 5,5 | 40 | 19 | 13 | 8 | 8 | 1 |
| WEALTH (R) | | | | | | | | |
| 250 000 | 2 | 3 | 3 | 7 | 9 | 5 | 2 | 2 |
| 600 000 | 1 | 2 | 7 | 2 | 15 | 5 | 1 | 0 |
| 950 000 | 0 | 5 | 9 | 12 | 5 | 4 | 1 | 2 |
| Total number | 3 | 5 | 19 | 21 | 29 | 14 | 4 | 4 |
| % | 3 | 5 | 19 | 21 | 29 | 14 | 4 | 4 |

With respect to annual income risk, the highest frequency (40 %) of decision makers has RACs between -0,00017 and 0 (risk group 3). Risk groups 4 and 5 were also well represented with respectively 19 and 13 % of the preferences. In total there was only one preference that fell in the most risk-averse interval (0,003 to $+\infty$) used. At the other end of the scale there were five preferences in total that fell in the most risk-seeking interval ($-\infty$ to -0,00017) used.

The frequency distribution of wealth risk preferences is also presented in Table 4.3. The largest number of decision makers was categorized in the middle section of the risk-aversion scale (risk groups 3, 4 and 5). In total, only three wealth risk preferences fell in the most risk-seeking interval used, and four preferences in the most risk-averse interval used.

It is obvious that both the annual income and wealth risk preferences were concentrated in risk groups 3, 4 and 5, where 72 % of the annual income preferences and 69 % of the wealth risk preferences were located.

The income and wealth risk preferences elicited in both the first and second rounds were tested in pairs to determine whether RACs remain constant over increasing/decreasing levels of income and wealth. Income/wealth levels 1 and 2 were first compared, followed by income/wealth levels 1 versus 3 and 2 versus 3. The results of these tests using the second round's elicitation results are presented in Table 4.4.

Table 4.4 Determination of increasing, constant or decreasing absolute risk aversion using second round elicitation as annual income/wealth increases, 1993

| | INCOME/WEALTH LEVELS | | | | | |
|---|---|---|---|---|---|---|
| | 1 VS 2 | | 1 VS 3 | | 2 VS 3 | |
| PERFORMANCE MEASURE | Z | (P) | Z | (P) | Z | (P) |
| BTNI (Second) | +3,15 | (0,002) | +3,62 | (0,0003) | +0,24 | (0,81) |
| NPV (Second) | -0,66 | (0,51) | -0,57 | (0,57) | -0,003 | (1,00) |

The positive signs provide some evidence from the positive signs that decision makers became more risk averse as the BTNI level increased. However, this increase in risk aversion was not consistent. For example, the increase in risk aversion is highly significant if one compares risk preferences elicited around BTNI levels 1 (R0) and 2 (R60 000), as well as between BTNI levels 1 and 3 (R120 000). Risk attitudes remained fairly unchanged when BTNI increased from R60 000 to R120 000, producing an insignificant z-value ($p = 0{,}81$). Similar results were obtained from testing risk attitudes obtained in the first round elicitations. First round elicitations, between the three BTNI levels, produced z-values at significance levels of 0,00009; 0,00006 and 0,53 respectively.

Due to the absence of an increase in risk aversion between BTNI levels 2 and 3, the null hypothesis that decision makers will have constant RACs over increasing levels of annual income, could not be rejected.

Decision makers were inclined to place more emphasis on positive (higher) ends of the distributions when BTNI values were very low (BTNI level 1), compared to BTNI distributions at higher BTNI levels. This resulted in the relatively strong risk-seeking behaviour expressed around BTNI level 1, compared to the BTNI levels 2 and 3. Decision makers were thus inclined, at such a low BTNI level, to take more risk than they would normally do at higher monetary outcomes. There were, for example, 20 risk-seeking decision makers (risk groups 2 and 3) around BTNI level 1. The number of risk-seeking decision makers declined to respectively 15 and 11 at BTNI levels 2 and 3.

With respect to changes in risk aversion with wealth, the Wilcoxon Test produced very small z-values that were all statistically insignificant at a 95 % significance level, except for risk attitudes elicited in the first round elicitation between NPV levels 1 and 3, where a significant z-value of 2,13 (p = 0,03) was obtained. Little evidence was found that decision makers displayed decreasing absolute risk aversion as the level of wealth increased. Because only one of the test results was statistically significant, the null hypothesis, namely that decision makers will have constant RACs over increasing levels of wealth, could not be rejected.

This research provided very little support for Arrow's (1971) hypothesis that decision makers will have decreasing absolute risk aversion over an increasing level of wealth. However, some support was found for increasing absolute risk aversion with increasing annual income levels. Both the studies of Tauer (1986) and Wilson and Eidman (1983) came to similar conclusions, namely that there is not much support for Arrow's hypothesis. Their tests were, however, only a "rough" approximation, because they used income instead of wealth as the argument in the utility function.

### 4.4.3 Consistency of annual income and wealth-risk preferences

The number of decision makers that passed the consistency test increased from about 77 % at the first income level to 81 % and 90 % at income levels around R60 000 and R120 000. The same pattern was observed in the wealth risk elicitations where 71 % of the decision makers were consistent on the first wealth level. The passing rate increased to 85 % and 98 % at wealth levels of R600 000 and R950 000. The increase in consistency as the level of annual income increased was also observed by Wilson and Eidman (1983), Tauer (1986) and Meiring and Oosthuizen (1993). Possibly the reason for the increase in consistency at higher levels of income can be contributed to clearer (bigger) differences among the distributions at higher income levels (Meiring and Oosthuizen, 1993).

## 4.5 CONCLUSIONS

It was determined that decision makers are more risk averse in their attitudes towards wealth risk than in their attitudes towards annual income risk.

The bounded risk-aversion intervals used in the annual income and wealth risk-aversion measurement scales were able to account for most of the risk preferences expressed by irrigation farmers in the Winterton area, with only a few farmers being placed in the extreme (unbounded) risk-seeking or risk-averse intervals. These risk-aversion coefficients can be used in economic analyses to identify risk-efficient management strategies for irrigation farmers in the Winterton area with non-neutral risk preferences.

Risk preferences of most irrigation farmers in the Winterton area were located around risk neutrality. However, there were some decision makers with strong risk-seeking and risk-averse preferences, especially among the decision makers that were not consistent. It is, therefore, important to apply consistency criteria in order to obtain credible risk-seeking and risk-averse RACs for use in risk analyses.

RACs did not increase or decrease as the level of wealth increased from the low to the high levels. There was some tendency towards increasing RACs as annual income levels increased. The magnitude and direction of change in the RACs depended on the outcome variable used (income or wealth) and the outcome levels selected.

The consistency with which risk preferences were elicited increased as the level of the outcome variable (income and wealth) increased. However, the consistency with which wealth risk preferences were measured did not differ from that of the annual income elicitations.

## 4.6 IMPLICATIONS FOR FURTHER RESEARCH

The reason for the differences between annual income and wealth risk preferences requires further investigation. The use of wealth and income amounts such that the wealth level is always the same multiple of the income level could be helpful in this regard. Different ways of explaining the wealth concept should also be investigated.

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# CHAPTER 5

# THE VALUE OF IRRIGATION INFORMATION FOR DECISION MAKERS WITH NON-NEUTRAL RISK PREFERENCES UNDER CONDITIONS OF UNLIMITED AND LIMITED WATER SUPPLY

JHF Botes, DJ Bosch and LK Oosthuizen

## 5.1 INTRODUCTION

The scheduling of irrigation water in the Winterton area is a very important matter to both the farmers and irrigation boards. Frequent irrigation water shortages occur, because of an over-utilization of water resources in the area. An irrigation-scheduling service which provides highly sophisticated irrigation information was introduced in the research area in an attempt to increase irrigation efficiency. Bosch, Eidman and Oosthuizen (1987) noted that better information about the crop and its environment has potential to help irrigation farmers in improving the economic efficiency of water and energy use. However, irrigation farmers are still using a wide range of irrigation-scheduling strategies which differ in terms of the type and amount of soil-water, plant-growth and weather information used.

Irrigation farmers are hesitant to use the more sophisticated irrigation-scheduling information, because of uncertainties about the economic value of better irrigation information, especially if the availability of irrigation water is uncertain. Farmers, farm advisors and research institutions need to know what the returns from better irrigation information are in order to evaluate scheduling services and/or to determine whether public expenditure on information systems should be increased (Bosch and Lee, 1988). The comprehensive and dynamic approach, developed and demonstrated in Chapter 3, was used to determine the value of better irrigation information to risk-neutral decision makers. English (1981), however, illustrated the importance of considering risk attitudes of irrigators when assessing information, by showing that strategies which maximized expected profit, did not maximize expected utility for all farmers. This research expands on previous work by using a comprehensive dynamic approach to value irrigation information for decision makers with different risk preferences when the availability of irrigation water is limited.

The objectives of this research were the following:

1) To determine how much irrigators with non-neutral risk preferences can pay to obtain more sophisticated soil-water, plant-growth and weather information under conditions of unlimited and limited water supply.
2) To determine to what extent factors such as the availability of irrigation water and the amount of plant extractable soil water (PESW) influence the value of irrigation information for decision makers with non-neutral risk preferences.
3) To establish to what extent changes in the absolute risk-aversion coefficients (RAC) affect the value of irrigation information.
4) To evaluate the effect of perfectly negatively correlated yields and product prices on the value of information.

## 5.2 CONCEPTUAL MODEL

### *5.2.1 Calculating the value of information for risk-neutral decision makers*

It is assumed that risk-neutral decision makers maximize expected profits. Profit $\pi$ is given by a profit function, $\pi(x,\Theta)$, where x is inputs into the decision process, $\Theta$ is a probability distribution function of stochastic variables (Byerlee and Anderson, 1982). Information on $\Theta$ will affect the decision inputs (x), and consequently result in a change in $\pi(x,\Theta)$.

A decision maker that uses little or no information will select decision variables so that expected profits from using the no-information strategy are maximized. Mathematically[1] this is equivalent to

$$\text{Max } E[\pi(x,\Theta)] = \int_{\Theta} \pi(x^*,\Theta)p(\Theta)d(\Theta) \qquad (1)$$

where $x^*$ is the set of decision variables which maximizes expected profits, and $p(\Theta)$ is the probability distribution function of stochastic variables from using the no-information strategy.

1. Calculation procedures are in part adopted from Mazzocco, Mjelde, Sonka, Lamb and Hollinger (1992) and Byerlee and Anderson (1982).

More sophisticated information provides the decision maker with a predictor which changes the probability distribution function of stochastic variables obtained from using little or no information, to $p(\Theta|k)$. The optimization problem for the better-information strategy is now given by

$$\text{Max } E[\pi_k(x,\Theta)] = \int_k \int_\Theta \pi(x_k,\Theta)p(\Theta|k)d(\Theta)d(k) \quad (2)$$

where $x_k$ is the set of decision variables which maximizes expected profits given the prediction k, and $p(\Theta|k)$ is the probability distribution function of the stochastic variable $\Theta$ given the prediction k.

The expected value of the predictor k is the amount of increase in expected profits resulting from using better information. Thus, the expected value of the predictor k is given by

$$\text{Value of } k = \int_k \int_\Theta \pi(x_k,\Theta)p(\Theta|k)d(\Theta)d(k) - \int_\Theta \pi(x^*,\Theta)\, p(\Theta|k)d(\Theta) \quad (3)$$

where Equation 3 represents the difference between the expected profits using better information ($E[\pi_k(x,\Theta)]$) and expected profits using little or no information ($E[\pi(x,\Theta)]$). If $E[\pi_k(x,\Theta)] = E[\pi(x,\Theta)]$, better information provided by k has no value for a risk-neutral decision maker.

### 5.2.2 Accounting for risk attitudes when valuing information

According to Bosch, Eidman and Oosthuizen (1987), the assessment of information for non-neutral risk preferences is a problem, because the difference between expected utility with information and expected utility without information cannot be used directly as the value of information for different decision makers. The reason is that utility is only unique up to a positive linear transformation (Hey, 1979).

In order to overcome the problem, Lavalle (1968) converted the value of information into a monetary measure. He determined the maximum amount an expected-utility-maximizing decision maker could afford to pay for information as the difference between the minimum the decision maker having no information would accept in return for not deciding and not receiving a payoff and the maximum the individual, upon receiving the information, would pay to buy back the right to decide and receive a payoff (Bosch and Eidman, 1987).

Bosch (1984) and Bosch and Eidman (1987) demonstrated how the value of information could be empirically estimated using generalized stochastic dominance (GSD).

Generalized stochastic dominance (GSD) was developed by Meyer (1977) using the theory of expected utility (Von Neumann and Morgenstern, 1947). The expected utility model states that distribution g is dominated by distribution f if the expected utility of distribution f is greater than the expected utility of distribution g. Mathematically[2], this is equivalent to

$$\int_{0}^{1} [G(x) - F(x)]\, U'(x)d(x) > 0 \qquad (4)$$

where F and G are the cumulative probability density functions of f and g, and U'(x) is the first derivative of the utility function with respect to x. By minimizing equation 4; *e.g.*, that the minimum value of equation 4 > 0, it can be proven that all individuals in the interval will prefer F to G.

Instead of working with a specific utility function, Meyer (1977) expresses utility by defining an upper bound, $r_2(x)$, and a lower bound, $r_1(x)$, on the absolute risk-aversion function, -U"(x)/U'(x). Meyer (1977) then proves, by optimal control, that function (4) is minimized by $r_1(x)$ if:

$$\int_{x}^{1} [G(x) - F(x)]\, U'(x)d(x) < 0 \qquad (5)$$

and by $r_2(x)$ if:

$$\int_{x}^{1} [G(x) - F(x)]\, U'(x)d(x) \geq 0\,. \qquad (6)$$

Bosch and Eidman (1987) compare distributions generated with and without information for a group of decision makers by using Meyer's criteria (GSD). The value of information is estimated as that amount by which each element of a net income distribution generated with information can be lowered before it no longer dominates the net income distribution generated without information. This is done as follows. A decision rule, i, is selected, *e.g.*, to initiate irrigation at a 50 % depletion level. The *ex ante* value of information, $V_i$,

2. Calculation procedures are adopted from Bosch (1984).

using decision rule i is then calculated by finding an amount $V_i$ such that equations (7) and (8) *(inequalities) are satisfied simultaneously:*

$$\int_0^1 [G(x) - F_i(x - V_i)]\ U'(x)d(x) > 0 \qquad (7)$$

$$\int_0^1 [G(x) - F_i(x - V_i - y)]\ U'(x)d(x) \leq 0 \qquad (8)$$

subject to

$$r_1(x) \leq -U''(x)/U'(x) \geq r_2(x) \qquad (9)$$

where $F_i$ and G are the cumulative net income distributions with and without information, respectively; x is net income; U is a Von Neuman-Morgenstern utility function; $V_i$ is the value of information that generates $F_i$ using decision rule i; and y is a small positive amount (Bosch and Eidman, 1987).

The two distributions are first compared with $V_i$ equal to zero to determine whether the no-information distribution, G(x) is dominated by the distribution generated with information, F(x). If so, $V_i$ is augmented by y until inequalities (7) and (8) are satisfied (Bosch and Eidman, 1987).

From the above it is clear that the optimum scheduling rule, $i^*$, that maximizes the value of information, $V_i^*$, for a specific group of decision makers, identified by their absolute risk-aversion coefficients, must be identified such that:

$$V_i^* \quad = \quad \max\ (V_i\text{: } i = 1,2....n) \qquad (10)$$

where n is the number of strategies evaluated for a given level of information and $V_i^*$ is the lower bound of the value of information to decision makers bounded by the lower and upper bounds of the absolute risk-aversion interval used. The value of information may, however, be higher for some of the decision makers in the risk-aversion interval (Bosch and Eidman, 1987).

### 5.2.3 Conclusions from the literature

Techniques used to determine what decision makers can pay to obtain better information must take risk preferences of decision makers into account. The reason is that there almost always is a trade-off between risk and returns. Higher levels of returns are accompanied by higher levels of risk (Blake, Caulfield, Fisher and Lea, 1988).

The *ex ante* instead of the *ex post* approach should be used to calculate the willingness to pay for better irrigation information (Chavas and Pope, 1984). The reason is that the *ex post* assessment of the value of information deals with the historical values of information and consequently does not account for the uncertainties of making real-time decisions.

The value of irrigation information will depend on the extent to which economic decisions can be improved if better information is used. It is therefore important that decisions made should maximize the value of information. A comprehensive, dynamic approach is needed to maximize expected utility for decision makers whose management decisions are made by using specific information strategies.

The value of information must be calculated at farm level, because costs and returns from non-irrigated and livestock enterprises may be correlated with irrigation returns and hence affect the value of information.

This research will expand the literature by developing research procedures to value information under risk when the availability of irrigation water is limited.

## 5.3 EMPIRICAL MODEL

The procedure used to calculate the value of irrigation information under unlimited and limited water supply conditions on two soil types in the Winterton area, for decision makers with non-neutral risk preferences required firstly, the construction and budgeting of a representative irrigation farm in the Winterton area; secondly, the identification of irrigation-information strategies; thirdly, the selection of absolute risk-aversion coefficients for risk-seeking and risk-averse decision makers; fourthly, adjusting the SIMCOM model to optimize expected utility as the principal-performance measure for each information strategy, risk preference, water availability scenario and soil type; and, finally, estimating the value of information. The GSD program of Cochran and Raskin (1988) was used to calculate the value of better irrigation information.

### 5.3.1 A representative irrigation farm in the Winterton area[3]

Fifty-three irrigation farmers in the Winterton area were interviewed by questionnaire. Information about the farmer, farming business, fixed and variable resources, financial situation and production system was obtained. This information was processed and analyzed to identify a representative fixed and variable-resource situation.

A representative irrigation farm with 170 ha maize under centre pivot irrigation, 50 ha dry-land maize, 30 ha kikuyu/ryegrass pastures under a drag line irrigation system and 300 ha grazing was identified in the Winterton area. A 100 cow-calf beef production unit along with 160 head of cattle, bought annually on a speculation basis to utilize the kikuyu/ryegrass pastures and maize stubble, are the other enterprises on the representative farm.

One hundred and seventy hectares are irrigated by centre pivot systems with a gross application capacity of 6,5 mm per day. A 30 ha drag line system is used to irrigate the kikuyu/ryegrass pastures. *An application efficiency of 80 % was used to convert gross* applications to net irrigation amounts.

The dry-land maize is produced on an Avalon/Bergville soil with a rooting depth of 800 mm and a plant extractable soil water content (PESW) of 77 mm. Two soils were selected for the irrigation enterprises to determine how the PESW affects the value of irrigation information. The first is the same soil used under dry-land conditions (Avalon) and the second is a Hutton/Doveton soil with a rooting depth of 1 050 mm and a PESW of 138 mm.

Total overhead cost was calculated at R401 304, which consisted of R140 439 depreciation, R23 116 insurance, R137 576 interest and R100 173 other miscellaneous overhead expenses (electricity, water and labour cost). It was determined that only a small percentage of the irrigation farmers received off-farm income (OFI).

Production cost (PC) for dry-land and irrigation maize enterprises was calculated at R822 and R1 198, respectively. The PC for irrigation maize was not adjusted under conditions of limited water supply, because of the high maize yield potential even in years of limited water supply. Irrigation variable cost (IC) and harvesting variable cost (YC) were calculated separately. IC was calculated at 64 cents per millimetre water applied per

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3. A detailed discussion of the procedures used in the construction of the representative farm, as well as the budgeting procedures and enterprise budgets is presented in Appendix B.

hectare and harvesting cost at R54,78 per harvesting hour and R0,154/ton/km over a distance of 30 km from farm to market. Production cost for the 100 head cow-calf production unit and 60 head of speculation cattle on kikuyu/ryegrass pastures amounts to R70 117. The production cost for 100 head of speculation cattle on the maize stubble was calculated at R8 541. Maize used in the feedpen was included in the budgets on a production cost basis, *e.g.*, 800 kg of maize per head of cattle in the feedpen, fattened over a period of three months, were transferred from the irrigation maize enterprise to the beef enterprise.

Irrigation water was first assumed to be available in unlimited quantities. The effect of limited water on the value of information was studied by introducing a 50 % restriction on the amount of irrigation water used by the irrigation farmers using little or no irrigation information to schedule irrigation water.

### 5.3.2 Information levels

Six irrigation-scheduling strategies were formulated by using different combinations of soil-water, plant-growth and weather information[(4)]. The first irrigation-information strategy used no or very little soil-water, plant-growth or weather information (no-information strategy). This no-information strategy was used as a benchmark strategy to assess the more sophisticated information strategies. The no-information strategy used no formal measuring method to determine when and how much to irrigate, but applied enough irrigation water to minimize the change of plant-water stress occurring during the growth season. Irrigation farmers using the no-information strategy, under limited water supply conditions, reduced the application amount and/or extended the time between irrigations.

Irrigation-Information Strategy 2 (checkbook strategy) used a combination of weather information and soil-water information to schedule irrigations. The amount of water in the soil at the beginning of the season is determined by using the feel or appearance of the soil. Daily information on the potential evapotranspiration (Eo) is collected and used to calculate the amount of water evapotranspirated (ET) out of the soil. Once a week the soil water content is corrected by the farmer. The feel or appearance method is used to adjust the soil water content to the nearest 10 mm of the actual soil water content. In addition, soil-water levels are corrected to the upper limit of PESW if the rainfall is more than 25 mm.

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4. See Chapter 3 for a more complete discussion on the characteristics of and differences between the six alternative irrigation-information strategies.

Irrigation-Information Strategy 3 based irrigation-scheduling decisions on soil-water information, while no or limited plant-growth and weather information are used. However, Strategy 3 assumed that daily soil-water levels cannot be measured accurately, because of measurement and sampling errors. As a result, Strategy 3 assumed that the error with which the daily soil water content was measured was uniformly and randomly distributed and not greater than 15 % of the PESW.

In contrast, Strategy 4 used perfect information about daily soil-water levels. Soil-water levels, as calculated by the crop-growth model were used. The perfect soil-water-information strategy was included to determine the increased returns from providing irrigation farmers with error-free soil-water information.

Irrigation-Scheduling Strategy 5, in addition to the perfect soil-water information of Strategy 4, used perfect weather information about the amount of rainfall over the next three days. Future rainfall was added to the amount of water in the soil. Irrigation was triggered if the soil water content and future rainfall values dropped below the trigger levels suggested by the SIMCOM model.

In addition to the information used by Strategy 5, Strategy 6 used information on the amount of water that would evapotranspirate over the next three days. The amount of water that would be lost over the next three days due to transpiration and evaporation if the plants were cultivated under dry-land conditions was obtained for each of the weather years by running the crop-growth simulation model. The ET values obtained from the crop-growth model were added for three days and written into the weather files. The future ET values were then used to adjust the soil water estimated used in Strategy 5 by subtracting the amount of water that would be lost under normal dry-land production conditions.

Each time one of the irrigation-information strategies indicated that an irrigation should be scheduled, an effective 10 mm of irrigation water was applied the next day. The one day lag accounted for the day the centre pivot irrigation system takes to reach halfway around the circle. The next irrigation could not be scheduled within two days of the first decision in order to allow the centre pivot system to apply the 10 mm of water that had already been scheduled.

### 5.3.3 Absolute risk-aversion coefficients

Annual income risk-aversion coefficients selected for irrigation farmers in the Winterton area, were elicited as discussed in Chapter 4. In order to simplify the analysis, farmers were classified into two risk groups; a risk-seeking group (RAC between -0,0003 and -0,00003) and risk-averse group (RAC between 0,00003 and 0,0003), RAC values of -0,0001 and 0,0001 were used in the optimization procedure to represent risk-seeking and risk-averse preferences, respectively. Specific RACs were used, because the complex model optimized expected utility at a specific utility point and not over a whole interval as specified by the interval approach (King and Robison, 1981).

In order to determine to what extent the strength of a decision maker's risk preference will affect the value of irrigation information, the selected RACs were divided by half, *e.g.*, from ±0,0001 to ±0,00005. The SIMCOM model was rerun only for Information Strategy 4 on both soils, using the reduced RAC.

### 5.3.4 The principal-performance measure optimized by the SIMCOM model

The SIMCOM model consisted of four distinct components; the optimization, irrigation, biological crop growth, and economic sub-models. The four parts of the model were linked through a series of operational relationships (Chapter 3). The three decision variables that were optimized ($X_1$, $X_2$ and $X_3$) represented the trigger levels (as percentages of PESW) in three different growth stages of the maize plant. The first growth stage is from germination to tassel, the second, from silk to early grainfilling, and the third from end grainfilling to physiological maturity.

Weather data for twenty years were obtained from a weather station in the Winterton area. The weather data were used in the SIMCOM model to simulate the yield and water use for the different irrigation-information strategies.

The SIMCOM model was changed from maximizing the expected value of a random before-tax net income (BTNI) distribution (Chapter 3) to maximizing expected utility. An exponential utility function was used to calculate the expected utility value for each year's BTNI value given the decision makers absolute risk-aversion coefficient. More specifically, the maximum expected utility for a risk-averse decision maker was calculated as follows:

$$\text{MAX EU(BTNI)} = \sum_{i=1}^{20} [- \text{EXP}((NR_{im} + NR_{dm} + NR_{bc} - OC) * -RAC) * Pr] \quad (11)$$

The BTNI for any given weather year was calculated by summing net returns received from beef cattle ($NR_{bc}$), dry-land ($NR_{dm}$) and irrigated maize ($NR_{im}$). Overhead cost

(OC) was then deducted. The negative exponent of the BTNI value, multiplied by the selected RAC, was then calculated, multiplied by its probability (Pr) and summed to similar values calculated from using all 20 of the weather years.

Net returns received from the irrigated maize enterprises for a specific year were calculated as follows:

$$NR_{im} = \sum_{i=1}^{20} [\{(IY_i * P_i) - PC_i - IC_i - YC_i\} * A_i] \tag{12}$$

where the variables represent the irrigated maize yields (IY), the producer price for maize (P), production cost (PC), irrigation variable cost (IC), yield variable cost (YC) and the area under production in a specific year ($A_i$).

The CERES maize (IBSNAT, 1986) crop-growth simulation model, which was built into the SIMCOM model, was used to simulate irrigation and dry-land maize yields using 20 years' weather data obtained from a weather station in Winterton. IC and YC were calculated in the economic subroutine depending on the amount of water irrigated and the yield obtained in a specific year.

Stochastic maize and beef prices were incorporated into the analysis to reflect price uncertainty. Beef prices were subjectively elicited, while the maize price scenario, developed by Meiring (1994), was used to obtain stochastic maize prices. A maize-beef price correlation coefficient of 0,321 was calculated and used in the @RISK program along with the maize and beef price scenarios to generate 20 correlated maize and beef prices. Each set of output prices was randomly assigned to different weather years. It was thus assumed that there was a zero correlation between the yields (weather years) and the product prices. This assumption was made because of a lack of data and the fact that the weather data collected represented only a very small area, especially considering the total area under maize production in Natal.

A sensitivity analysis was done to determine whether the correlation between yield (weather years) and product prices affects the value of irrigation information. A correlation coefficient of -1 was used, because intuitively years of high yield would correspond to low product prices. The SIMCOM model was rerun with the negatively correlated yield and product prices for Information Strategy 4, for both soil types and both water availability scenarios.

## 5.4 CALCULATING THE VALUE OF INFORMATION

The search for the optimal decision rule for initiating irrigation for a given irrigation-information strategy, as shown in Equation 10, is complicated, especially when irrigation water is limited. The SIMCOM model was therefore used to obtain the decision rule that yielded the highest expected utility value for a specific risk preference over the 20 replications. The optimized BTNI distributions for the different irrigation-information levels were then read into the GSD computer program which computed the value of information. The GSD program calculated the amount that each BTNI value in the distribution with the highest EU(BTNI) must be lowered to no longer dominate the EU(BTNI) distribution generated with a lower information strategy for risk-seeking, risk-neutral and risk-averse preferences.

## 5.5 RESULTS

### 5.5.1 The value of information for risk-seeking, risk-neutral and risk-averse decision makers

The value of better irrigation information for non-neutral decision makers in the Winterton area under conditions of unlimited and limited water supply on the Hutton (PESW=138 mm) and the Avalon (PESW=77 mm) soils are presented in Tables 5.1 and 5.2 respectively.

The maximum amounts risk-seeking, risk-neutral and risk-averse decision makers farming on the Hutton soil with unlimited water (Table 5.1), could pay for obtaining more sophisticated irrigation information were R143/ha, R136/ha and R330/ha, respectively. When, however, irrigation water was limited, the value of information increased by 60 % (R230/ha), 49 % (R202/ha) and 55 % (R511/ha) for the three types of decision makers, respectively.

The amount irrigation farmers could pay for obtaining better irrigation information increased as the type and quality of the soil-water, plant-growth and weather information increased. Diminishing returns to better information, however, are clearly demonstrated. For example, the checkbook-irrigation strategy (Strategy 2) on the Hutton soil with unlimited water (Table 5.1) was able to account for 93 % (R308/ha) of the increase in expected returns generated by Information Strategy 6 (R330/ha). The rest of the information strategies (Strategies 3 to 5) resulted in a mere 7 % increase in expected returns.

Table 5.1 The value of more sophisticated irrigation information for risk-seeking, risk-neutral and risk-averse decision makers under conditions of unlimited and limited water supply on Hutton soil (PESW=138 mm) in the Winterton area, 1993

| HUTTON SOIL | UNLIMITED WATER | | | LIMITED WATER | | |
|---|---|---|---|---|---|---|
| | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) |
| Strategy 2 | 138 | 124 | 308 | 226 | 168 | 0 |
| Strategy 3 | 142 | 119 | 310 | 230 | 186 | 164 |
| Strategy 4 | 141 | 128 | 311 | 230 | 196 | 320 |
| Strategy 5 | 142 | 129 | 321 | 230 | 202 | 511 |
| Strategy 6 | 143 | 136 | 330 | 230 | 193 | 351 |

Risk-seeking = absolute risk-aversion coefficients between -0.0003 and -0.00003
Risk-averse = absolute risk-aversion coefficients between 0.00003 and 0.0003

When water supplies were limited, decision makers proved unwilling to pay anything to obtain perfect plant-growth information and, consequently, also unwilling to pay for future ET information if they already had perfect soil water and future rainfall information (comparing Strategies 6 and 5). The reason why decision makers proved unwilling to pay for ET information when water was limited is to be found in the fact that the addition of future ET information did not increase the highest or lowest outcomes, nor did it increase the expected value of the BTNI distribution generated with perfect soil water and future rainfall information. In fact, the use of future ET information obtained under dry-land production conditions caused a decline in the value of information for the risk-neutral and risk-averse decision makers. The decline in the value of information may have been the result of a slower than anticipated depletion in the soil-water levels. The result was that irrigation was triggered earlier in the growth stage when the effects of water stress on crop yield are less severe causing severe yield losses later in the growth season when irrigation water became limited.

If irrigation water is unlimited, the value of information increases as risk preferences change from risk seeking to risk averse on both the soil types. On the Hutton soil (Table 5.1) for example, the value of information for Strategy 6 increased by 130 % from R143/ha to R330/ha when risk preferences changed from risk seeking to risk averse. Similarly, the increase in the value of information on the Avalon soil (Table 5.2) was also

130 % (from R219/ha to R503/ha) when risk preferences changed from risk seeking to risk averse.

Table 5.2 The value of more sophisticated irrigation information for risk-seeking, risk-neutral and risk-averse decision makers under conditions of unlimited and limited water supply on Avalon soil (PESW=77 mm) in the Winterton area, 1993

| AVALON SOIL | UNLIMITED WATER | | | LIMITED WATER | | |
|---|---|---|---|---|---|---|
| | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) |
| Strategy 2 | 205 | 147 | 469 | 637 | 231 | 85 |
| Strategy 3 | 209 | 153 | 475 | 637 | 319 | 381 |
| Strategy 4 | 213 | 157 | 481 | 638 | 330 | 382 |
| Strategy 5 | 212 | 161 | 482 | 638 | 331 | 601 |
| Strategy 6 | 219 | 173 | 503 | 639 | 332 | 362 |

Risk-seeking = absolute risk-aversion coefficients between -0.0003 and -0.00003
Risk-averse = absolute risk-aversion coefficients between 0.00003 and 0.0003

The reason for the significant increase in the value of information is that better information succeeds in increasing the lowest outcomes of the BTNI distribution more than it increases the highest outcomes of the BTNI distribution obtained from the benchmark strategy (Strategy 1). For example, the use of Information Strategy 6 by risk-seeking decision makers on the Hutton soil with unlimited water, resulted in the highest outcome of the benchmark strategy, increasing by R142/ha. When, however, Information Strategy 6 was used by risk-averse decision makers, under similar conditions, the lowest outcome of the benchmark strategy decreases by R330/ha.

In general, under limited water supply conditions, the value of information decreases as risk aversion increases. For example, the value of information for all the information strategies on Avalon soil with limited water (Table 5.2) was lower for risk-averse decision makers than for risk-seeking decision makers. The value of perfect soil-water, future rainfall and future ET information (Strategy 6) was R277/ha lower than the R639/ha a risk-seeking decision maker could pay. Another example is the fact that risk-averse decision makers irrigating Hutton soil with limited water (Table 5.1) proved unwilling to pay anything for obtaining the information used by the checkbook-information strategy (Strategy 2), whereas a risk-seeking decision maker could pay up to R226/ha. Better irrigation information, when irrigation water is limited, succeeds in producing bigger improvements in the highest BTNI values compared to the improvements on the lower end of the BTNI distribution, consequently it has a higher value for risk seekers than risk averters.

The importance of the soil is reflected in the fact that the value of information, for all types of decision makers and information strategies, is higher on Avalon soil (PESW=77 mm) than on Hutton soil (PESW=138 mm). For example, the risk-seeking, risk-neutral and risk-averse decision makers farming on Avalon soil with unlimited water could pay up to 34, 27 and 52 % respectively more than the farmers farming on Hutton soil under similar conditions.

Irrigation farmers, by using better irrigation information, can reduce the adverse effects of irrigating poor soils. This is clearly illustrated by the information's ability to narrow the differences between the two soils. Information, therefore, is a partial substitute for soil quality.

Better irrigation information does not succeed in increasing the expected values to the same extent, as it does the highest or lowest values of the benchmark BTNI distributions. Consequently, the values of better irrigation information for risk-neutral decision makers are lower than the values of information for either the risk-seeking or risk-averse decision makers.

### *5.5.2 The effect of risk attitudes on yields and irrigation applications*

The expected maize yields and the amount of irrigation water applied by the different information strategies on Avalon soil under conditions of unlimited and limited water supply for non-neutral decision makers are presented in Table 5.3[(5)]. The results presented in Table 5.3 (also Table C1, Appendix C) indicate that information and risk attitudes affect the expected yields and amounts of water applied differently, depending on whether irrigation water is unlimited or limited.

The expected amount of irrigation water applied under unlimited water supply conditions increases as risk preferences change from risk seeking to risk averse. The expected amount of water applied by a risk-neutral decision maker using perfect soil-water information (Strategy 4) increased by 48 % from the 139 mm applied by a risk-seeking decision maker, to 206 mm. The expected irrigation amount increased by another 41 % to 290 mm when risk preferences changed to risk averse.

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5. The effect of risk attitudes on yields and irrigation amounts obtained on Hutton soil is presented in Table C1 (Appendix C).

Table 5.3 The expected maize yields (kg/ha) and the amount of irrigation water applied (mm/ha) by the identified information strategies, optimized by the SIMCOM model, on Avalon soil (PESW=77 mm) under unlimited and limited water supply conditions for risk-seeking, risk-neutral and risk-averse decision makers respectively in the Winterton area with a long-term average rainfall of 674 mm/year, 1993

| AVALON SOIL | UNLIMITED WATER | | | LIMITED WATER | | |
|---|---|---|---|---|---|---|
| | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING | NEUTRAL | AVERSE | SEEKING | NEUTRAL | AVERSE |
| Strategy 1 | | | | | | |
| Yield (kg/ha) | 9 464 | 9 464 | 9 464 | 8 416 | 8 416 | 8 416 |
| Water (mm/ha) | 306 | 306 | 306 | 148 | 148 | 148 |
| Strategy 2 | | | | | | |
| Yield (kg/ha) | 9 649 | 9 716 | 9 746 | 8 757 | 9 003 | 8 592 |
| Water (mm/ha) | 215 | 240 | 311 | 149 | 144 | 150 |
| Strategy 3 | | | | | | |
| Yield (kg/ha) | 9 355 | 9 645 | 9 732 | 8 842 | 9 231 | 8 712 |
| Water (mm/ha) | 158 | 197 | 342 | 150 | 146 | 116 |
| Strategy 4 | | | | | | |
| Yield (kg/ha) | 9 211 | 9 673 | 9 729 | 7 941 | 9 252 | 8 442 |
| Water (mm/ha) | 139 | 206 | 290 | 150 | 143 | 97 |
| Strategy 5 | | | | | | |
| Yield (kg/ha) | 9 487 | 9 669 | 9 698 | 8 840 | 9 247 | 9 238 |
| Water (mm/ha) | 160 | 197 | 266 | 149 | 135 | 137 |
| Strategy 6 | | | | | | |
| Yield (kg/ha) | 9 547 | 9 695 | 9 732 | 7 812 | 9 238 | 9 016 |
| Water (mm/ha) | 171 | 196 | 252 | 150 | 145 | 120 |

The yields obtained with unlimited water increased slightly as risk aversion increased. Expected yields generated by the perfect information strategy increased from 9 211 kg/ha for the risk-seeking decision maker, to 9 673 kg/ha for the risk-neutral decision maker and to 9 729 kg/ha for the risk-averse decision maker. The rise in expected yields reflects the risk-averse decision maker's willingness to adjust the depletion levels of the information strategies so that enough irrigation water is applied in the dry weather years so as not to adversely affect the expected yield.

The expected yields stayed close to the maximum potential yield under unlimited water conditions, as the type and quality of soil-water, plant-growth and weather information improved. In contrast, the amount of irrigation water applied, decreased by 44, 36 and 18 % for risk-seeking, risk-neutral and risk-averse decision makers, respectively as the sophistication of the irrigation information increased.

Contrasting results are obtained when irrigation water is limited. The yields and irrigation water amount are more variable and the effects of risk preferences less visible. However, yields generated by the more sophisticated information strategies (Strategies 4 to 6), tend to be higher for risk-averse decision makers than for risk-seeking decision makers. The expected amount of irrigation water applied, on the other hand, tends to decrease if risk preferences change from risk seeking to risk averse. The rise in expected yields, notwithstanding the fact that less water is applied, reflects the risk-averse decision makers' willingness to adjust the depletion levels of the information strategies used, so that enough irrigation water is applied later in the growing season. By delaying the application of irrigation water, risk averters make sure that they have adequate irrigation water supplies left for irrigation in the very dry weather years, thus increasing income at the lower end of the CDF.

### 5.5.3 A sensitivity analysis of the effect of moderate risk preferences on the value of perfect soil-water information

In Table 5.4[6] the values of perfect soil-water information (Strategy 4) on Avalon soil for decision makers with moderate risk preferences (RAC = ±0,00005) are compared with the amounts a decision maker with strong risk preferences (RAC = ±0,0001) could pay.

Table 5.4 A sensitivity analysis on the effect of moderate risk preferences (RAC = ±0,00005) on the value of perfect soil-water information (Strategy 4) on Avalon soil (PESW=77 mm) in the Winterton area, 1993

| STRATEGY 4 ON AVALON SOIL | UNLIMITED WATER | | LIMITED WATER | |
|---|---|---|---|---|
| | RISK PREFERENCES | | RISK PREFERENCES | |
| | SEEKING (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | AVERSE (R/ha) |
| RAC = ±0,0001 | 213 | 481 | 638 | 382 |
| RAC = ±0,00005 | 214 | 445 | 631 | 378 |

The value of perfect soil-water information for risk-seeking decision makers proved insensitive to a 50 % reduction in the RAC used. There is, however, a slight tendency for the value of information to decrease somewhat for moderate risk-preferring decision makers if irrigation water supplies become limited. The biggest decline in the value of perfect soil-water information is for moderately risk-averse decision makers who proved

6. The effect of moderate risk preferences on the value of perfect soil-water information on Hutton soil is presented in Table C2 (Appendix C).

only willing to pay R445/ha compared to the R481/ha the strongly risk-averse decision maker could pay. A similar pattern is observed as regards Hutton soil (Table C2, Appendix C) where the decline was also about 7 % under unlimited water supply conditions and about 18 % when irrigation water was limited. The value of better irrigation information, especially under unlimited water supply conditions, proved to be not very sensitive to the size of the RAC selected to represent risk-seeking or risk-averse preferences.

### 5.5.4 The effect of perfectly negatively correlated yield and product prices on the value of perfect soil-water information

In Table 5.5[7] the values of perfect soil-water information (Strategy 4) on Avalon soil, when no correlation between product prices and weather years was assumed, are compared with the value of perfect soil-water information when perfectly negative correlation between yield and product prices was assumed (correlation = -1).

Table 5.5 The effect of perfectly negatively correlated yield and product prices on the value of perfect soil-water information (Strategy 4) on Avalon soil (PESW=77 mm) in the Winterton area, 1993

| STRATEGY 4 ON AVALON SOIL | UNLIMITED WATER | | | LIMITED WATER | | |
|---|---|---|---|---|---|---|
| | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) |
| correlation = 0 | 213 | 157 | 481 | 638 | 330 | 382 |
| correlation = -1 | 163 | 165 | 325 | 234 | 348 | 467 |

The value of information for decision makers with non-neutral risk preferences is sensitive to the correlation used between yields and product prices. For example, the value of perfect soil-water information proved to decrease by 23 and 32 %, respectively, for risk-seeking and risk-averse decision makers if irrigation water is not limited. The reason for the decrease in the value of information for risk averters is that low yields are now accompanied by higher prices. Thus, the lower end of the BTNI distribution is now higher than it was before and the relative impact of information on lower incomes is now less. A similar explanation can serve to explain the decline in information value for risk

7. The effect of perfectly negatively correlated yield and product prices on the value of perfect soil-water information on Hutton soil is presented in Table C3 (Appendix C).

seekers. However, the impact of correlated yield and prices is now at the higher end of the BTNI distribution.

However, the negatively correlated yields and product prices do not always diminish the value of information. The value of information for a risk-averse decision maker proved to increase by 22 % under limited water from R382/ha to R467/ha if yield and product prices are perfectly negatively correlated.

On the other hand, the value of information to risk-neutral decision makers, is not very sensitive to the correlation between yield and product prices. Negatively correlated yield and product prices resulted in a small increase in the value of information to the risk-neutral class for all the production conditions evaluated.

The effect that price-yield correlations have on the value of information can be affected by the specific price vector drawn. The effect of price-yield correlations on the value of information, should therefore be evaluated more completely by drawing multiple price vectors under alternative assumptions about the price-yield correlations in order to see if statistically significant patterns emerge.

## 5.6 CONCLUSIONS

The maximum amounts irrigation farmers in the Winterton area farming without any water restrictions could pay for obtaining the highest level of soil-water, plant-growth and weather information varied between R136/ha and R330/ha, depending on risk preferences. If however, irrigation water becomes limited, the value of better irrigation information was shown to increase by at least 49 % to vary between R202/ha and R511/ha. If the PESW is lowered (Avalon soil), the value of better information increases by at least 27 % to vary between R173 and R503.

The amount that irrigation farmers could pay for better irrigation information increased as the level and quality of information increased, however, the value of information increased at a diminishing rate.

It was revealed that the amount irrigation farmers could pay for better irrigation information depends on their risk attitude. Under unlimited water supply conditions the amount irrigation farmers can pay, increases by 130 % if risk preferences change from risk seeking to risk averse. However, the opposite is observed if irrigation water is limited and the soil has a low PESW. Under these conditions the value of information is about 57 % lower for risk-averse decision makers compared to risk-seeking decision makers. The lower information values for risk-averse decision makers may be due to the fact that better information produces larger increases in the highest outcome values compared to the lowest outcome values of the benchmark BTNI distribution.

The amount irrigation farmers could pay for obtaining better irrigation information proved to increase substantially if the availability of water is limited. However, the value of information becomes much more sensitive to the soil's PESW, the risk preferences of the decision makers and the level and quality of irrigation information used. The interaction between timing of irrigation water and yield reductions (or expected value, or expected utility) becomes much more important if irrigation water is limited.

It was found that better irrigation information greatly reduces the adverse affects of limited water by adjusting the timing of irrigation water so that the maize yields, and consequently net returns, are not adversely affected. Better information, therefore, can be used as a substitute for the availability of irrigation water.

The value of information for all information strategies and risk preferences proved to be higher on Avalon soil than Hutton soil. The use of information strategies that provide irrigation farmers with more sophisticated irrigation information, however, was shown to reduce the differences between the two soils with respect to the value of information. It was also found that better irrigation information can greatly reduce the adverse effects of the low PESW by adjusting the time of irrigation, so that the maize yields, and consequently net returns, are not adversely affected. Better information, therefore, can be used as a partial substitute for the quality of irrigation land.

The value of irrigation information was shown to be not very sensitive to changes in the absolute risk-aversion coefficients (RAC) used to represent risk-seeking or risk-averse preferences. A 50 % reduction in the RAC used resulted in a maximum increase of 8 % in the value of information.

The effect of perfectly negatively correlated yield and product prices on the value of information was found to depend on the risk attitudes of the decision makers. The value of irrigation information for risk-neutral decision makers is not greatly affected by assuming a perfectly negative correlation between yield and product prices. By comparison, the value of information for non-neutral risk preferences shows greater variation (both up and down) if yield and product prices are perfectly negatively correlated.

## 5.7 IMPLICATIONS FOR FURTHER RESEARCH

The value of information for other farm types and areas should be determined. The sensitivity of the value to changes in enterprise selection, farm size and other important economic variables should be determined.

These findings regarding the value of information might be verified by using, for example, the contingent valuation method (Brookshire and Crocker, 1981). The farmers in the Winterton area might be asked questions (by playing a bidding game) in an attempt to determine their willingness to pay for better irrigation information.

Greater research attention needs to be given to the decision-making process of farmers. For example, do decision makers use the information they receive in an optimal manner? What are the information needs of the decision maker to successfully implement and operate a better irrigation-information strategy? Synthesizing information in this manner can also contribute to understanding why irrigation farmers often do not use socially desirable and economically productive management practices.

The focus of this research was to assess irrigation information on an annual basis, ignoring the possibility of learning over time. An extension of this work is to assess irrigation information on a real-time, multi-year basis to determine how the NPV of an irrigation decision is affected. The wealth risk preferences elicited in Chapter 3 can be used to assess irrigation information in such a setting.

The effect of price-yield correlations on the value of information should be further investigated by drawing multiple price vectors under alternative assumptions about the price-yield correlations and then determining whether statistically significant patterns emerge.

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# CHAPTER 6

## THE EFFECTS OF PUMPING RESTRICTIONS ON IRRIGATION EFFICIENCY: IMPLICATIONS FOR ESKOM'S TIME-OF-USE ELECTRICITY SUPPLY TO RURAL AREAS

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### 6.1 INTRODUCTION

The scheduling of irrigation water has long been seen as the most likely way irrigation efficiency can be increased. However, savings in the cost of electricity, can potentially also make a large contribution to increasing irrigation efficiency (Botes and Oosthuizen, 1991). ESKOM has developed a load management programme (Ruraflex) which supplies electricity to irrigation farmers at a reduced rate. In return, however, it is expected that irrigation farmers must restrict pumping time so that ESKOM can even out demand on their generating capacity.

Both the irrigation farmers and ESKOM are, however, unsure about the amount of incentive (cheaper electricity rates) which must be offered to irrigation farmers so that pumping restrictions caused by load management do not leave them worse off. The problem is further complicated by the fact that the minimum amount of incentive required will most likely depend on factors such as the soil's plant extractable soil water (PESW), the pumping capacity of the irrigation system and characteristics of the irrigation farmer such as risk aversion and the amount of attention devoted to scheduling management (Bosch and Eidman, 1988).

The objectives of this research were to:

1) supply background information on the Ruraflex electricity option;
2) determine how pumping restrictions affect the expected net returns, yields, the amount of irrigation water applied and the irrigation management of maize produced in the Winterton area;
3) determine the amount of incentive required by irrigation farmers with non-neutral risk preferences to prevent them from being left worse off by pumping restrictions; and

4) determine how factors such as the soil's PESW and the application capacity of the irrigation system influence the amount of incentive required by decision makers with non-neutral risk preferences.

## 6.2 RURAFLEX

### 6.2.1 What is Ruraflex

At present ESKOM provides seven electricity tariffs and three options to different consumers. Options refer to possible future tariffs which are being tested and made available to clients, whereas tariffs have passed the testing phase and have been proclaimed.

Of the seven electricity tariffs only four are available to irrigation farmers. These are tariffs A, E, F and D. Electricity tariffs do not utilize time periods but options do.

The options available for farming purposes are T2 and Ruraflex. Hager (1994b) makes it clear, however, that option T2 is being phased out with Ruraflex taking its place. The testing of option T2 was completed but it was possible to switch from another tariff and to save on electricity expenditure without transferring electricity consumption. Ruraflex was only introduced from March 1994 and is still in a testing phase. Unlike the usual tariffs Ruraflex is an option which takes the different times of day into consideration where the demand for electricity varies at the different times. This results in electricity being cheaper at certain times. Ruraflex can therefore be categorized as a time-of-use electricity tariff (TOU).

### 6.2.2 Motivation for the development of Ruraflex

TOU electricity tariffs provide lower electricity costs at times when the demand for electricity is low (Curley and Knutson, 1992:24). It also provides farmers with a means to adapt their irrigation patterns in such a way that they can save on electricity cost (Nef, 1989:1). Ruraflex was developed with a view to utilizing electricity as efficiently as possible.

TOU electricity tariffs are also developed in South Africa in order to encourage the use of electricity during normally off-peak times, the reason being that ESKOM finds it expensive to generate electricity during peak times. This means that ESKOM finds it less expensive to generate electricity when the demand is lower and can then supply it to farmers at a lower rate during these times. For the farmers this means a cut in electricity cost, while at the same time ESKOM cuts their own costs by spreading the demand.

### 6.2.3 The composition of Ruraflex

Ruraflex is available to all three phase rural clients with an installed capacity of up to 5 MVA, on rural networks in rural areas as determined by ESKOM from time to time and which accept supply from 400 V to 22 kV.

The costing components applicable to Ruraflex are a basic charge, an active energy charge, a reactive energy charge, a voltage discount, a transmission charge and the monthly rental. The basic charge is different for clients with a transformer of 50 kVA or less and one of 51 kVA up to 5 MVA.

The active energy charge differentiates between winter and summer and also between peak *time, standard time and off-peak time.* Peak *time rates are the highest, while off-peak* time rates are the cheapest. Reactive energy levies applicable to Ruraflex are only applied if the labour factor does not exceed 0,96.

Electricity tariff components can be divided into two groups. In the first place there are the variables which determine the access to the various electricity tariffs. These variables determine a consumers right to utilize a certain tariff and whether he should rather use another electricity tariff. The second group of components determine what every electricity tariff is composed of. Costs are therefore coupled to the different components. The two groups relevant to Ruraflex are subsequently discussed separately.

#### 6.2.3.1 Variables which determine access to Ruraflex

Ruraflex is only available to rural clients, *i.e.* clients not resident in urban areas. Rural areas are stipulated by ESKOM and vary from time to time. In addition, clients are required to use an installed capacity of up to 5 MVA and should accept supply of 400 V to 22 kV.

#### 6.2.3.2 Cost Components

According to Hager (1994c:107) there are various factors which influence the price of electricity and which the consumer eventually pays for. The first factor is the generation cost, which indicates the cost for the installation of power plants by ESKOM. The power plants are erected by ESKOM with a view to supplying the consumer with electricity when required. By paying for his electricity every consumer makes a contribution to the capital expenditure of these plants.

Since the largest number of power plants are situated in the Eastern Transvaal, electricity is distributed to other parts of the country by means of transmission networks. These networks are very expensive and the cost pertaining to them is recovered from all consumers (Hager, 1994c:107). The highest possible voltage is used to transmit the electricity in the most efficient manner. However, all consumers do not utilize the electricity at the high voltage, which means that the voltage level has to be decreased and the lower it becomes, the higher the transmission cost becomes. Thus, the voltage requirement has a further influence on the average price the consumer pays.

A fourth factor which has an influence on the cost of electricity, is the consumption pattern (Hager, 1994c:108). The consumption pattern reflects the consumer demand. The inconstant consumption pattern gives rise to variable prices for electricity since demand determines the number of power plants used in the generation of power. As a result of the long distances over which the electricity has to be distributed losses of up to 15 % occur (Hager, 1994c:108). These losses are also carried by the consumer. Other factors which influence the cost of electricity are, amongst others, support costs, locality and density of client distribution (Hager, 1994c:108).

The above factors are included in various components which constitute Ruraflex. These different components, as well as the different factors which influence the components, will be discussed next.

#### 6.2.3.2.1 Active energy charge

This is a charge payable on every kilowatt hour (kWh) consumed (ESKOM, 1994:1). It is therefore the kilowatts consumed per month, multiplied by the number of hours per month, multiplied by the rate. According to Bezuidenhout (1992) this charge covers the generation cost of electricity. Active energy charge is a variable cost item and is determined by the number of kilowatt hours consumed.

#### 6.2.3.2.2 Basic charge

The basic charge is payable every month whether electricity is used or not. It is therefore a fixed cost item and, according to Bezuidenhout (1992), it covers the cost of metres and computers, salaries of meter-readers and computer operators, as well as the processing of accounts.

#### 6.2.3.2.3 Monthly rental

Monthly rental goes towards the capital cost of putting up the network and is a fixed levy which the client pays on a monthly basis (ESKOM, 1994:1). This fee is recovered in one of three ways. In the first place the full amount can be recovered immediately. Secondly, partial payment can be effected immediately, with the balance being paid over a period of 25 years or less. The last method allows the client to reimburse the total cost over a period of 25 years or less.

#### 6.2.3.2.4 Reactive energy charge

This charge covers the cost of using electrical equipment to generate a magnetic field with which to activate a motor. (Hager, 1994a:87). The charge for the reactive energy will apply for every kilovar hour (kVarh) if it should exceed 30 % of the kilowatt hours used per month. The 30 % is normally covered by the basic charge. Thus, if a person's labour factor exceeds 0,96, he won't pay the reactive charge which makes it a variable cost.

#### 6.2.3.2.5 Voltage discount

In order to transmit electricity as effectively as possible, the highest possible voltage is used. This voltage is usually decreased to supply in the consumer's demand. A percentage discount is allowed for the different levels of supply voltage. The higher the voltage level, the higher the percentage discount will be. This discount is based on the active energy charge and is therefore variable. The four categories of supply voltage on which the percentage discounts are based, are (1) 0 V to 500 V; (2) 501 V to 65,9 kV; (3) 66 kV to 132 kV; and (4) in excess of 132 kV.

#### 6.2.3.2.6 Point of supply

EVKOM (1987:2) describes a point of supply as a point or position on the property of the consumer, or elsewhere, where electricity is supplied or will be supplied as agreed by ESKOM and the consumer.

#### 6.2.3.2.7 Transmission surcharge

The transmission surcharge is dependent on the distance from Johannesburg and is calculated as a percentage of the demand charge and energy charge of specific electricity tariffs. This charge is a variable cost item and is taken into account to cover the cost of transmission over long distances. The four different categories of distances from Johannesburg are (1) 0 to 300 km; (2) 301 to 600 km; (3) 601 to 900 km; and (4) further than 900 km.

#### 6.2.3.2.8 Time slot

Different times of day are specified with the objective of giving the consumer the opportunity to divert his electricity demand to cheaper time slots. ESKOM makes provision for three different time slots namely, peak time, standard time, and off-peak time. Peak time covers the times of day when the demand for electricity reaches a maximum and comprises 25 hours/week. Off-peak time, on the other hand, are those times when the demand reaches its lowest point and it covers 81 hours/week. The specific times are determined by ESKOM and a cost/kWh is specified for each of the time slots. The cost varies from very high during peak time to very low during off-peak time. Different rates apply because it is more expensive for ESKOM to generate electricity during peak times than during off-peak times. Costs coupled to the time slots, can be considered variable since it is based on kilowatt hours consumed.

In conclusion it becomes apparent that the cost components of Ruraflex can be divided into two groups. The first group comprises the fixed cost components which include the basic charge and the monthly rental. These components do not change during the year and have to be paid whether electricity is used or not.

The variable cost components make up the second group and include active energy charge, reactive energy charge and transmission charge, as well as the voltage discount. These components are directly or indirectly dependant on the number of kWh consumed during the month.

## 6.3 CONCEPTUAL MODEL

The effect that load management has on irrigation efficiency will depend on how pumping restrictions affect economic decisions (Bosch and Eidman, 1988). Irrigation management should therefore be adjusted so that the expected utility for each load management scenario is maximized. The net income distributions that maximize expected utility before and after introducing pumping restrictions, can then be compared to determine the amount of incentive required in order not to leave decision makers with different risk preferences worse off when restricting pumping hours.

Botes (1994) developed a simulation-optimization model (SIMCOM) which combines a crop-growth simulation model with an efficient search optimizer. The SIMCOM model was used to maximize the expected utility of six different irrigation-information scenarios over a 20 year period by searching for the optimal triggering levels in each of three growth stages. A risk efficiency criterion such as generalized stochastic dominance (GSD) (King and Robison, 1981) was used to determine the amount by which each value in a cumulative distribution function of net returns (CDF-NR) obtained from one load management scenario must be lowered (or increased) so that it no longer dominates (or is dominated by) the CDF-NR obtained from another load management scenario.

The risk preferences of irrigation farmers in the Winterton area were elicited by Botes, Bosch and Oosthuizen (1994). Absolute risk- aversion coefficients (RACs) of between -0,0003 and -0,00003 were identified for risk-seeking decision makers. RACs of between 0,00003 and 0,0003 were identified for risk-averse decision makers.

## 6.4 EMPIRICAL MODEL

The procedure used to calculate the amount of incentive required when pumping time is restricted for irrigation farmers with different risk preferences on two soil types, using irrigation systems with two application capacities in the Winterton area, requires firstly, adjustment of the SIMCOM model; secondly, selection of absolute risk-aversion coefficients; thirdly, budgeting of irrigated maize; fourthly, construction of alternative load management scenarios; and, finally, calculation of the amount of subsidy required under all anticipated production conditions.

The SIMCOM model was adjusted to optimize expected utility as the principal-performance measure for each load management scenario, risk preference, application capacity and soil type using 20 years' weather data from the Winterton area. More specifically, the maximum expected utility for a risk-averse decision maker was calculated as follows:

$$\text{MAX EU(BTNI)} = \sum_{i=1}^{20} [- \text{EXP} (NR_{im} * -RAC) * Pr] \qquad (1)$$

The BTNI for any given weather year was calculated by summing net returns received from 50 ha of irrigation maize ($NR_{im}$). The negative exponent of the BTNI value, multiplied by the selected RAC, was then calculated. This was multiplied by its probability (Pr) and summed to similar values calculated from using all 20 the weather years. RACs identified by Botes, Bosch and Oosthuizen (1994) for risk-seeking and risk-averse decision makers were used.

Net returns received from the irrigated maize enterprises for a specific year were calculated as follows:

$$NR_{im} = \sum_{i=1}^{20} [\{(IY_i * P_i) - PC_i - IC_i - YC_i\} * A_i] \quad (2)$$

where the variables represent the irrigated maize yields (IY), the producer price for maize (P), production cost (PC), irrigation variable cost (IC), yield variable cost (YC) and the area under production (A) in a specific year (i).

The CERES maize crop-growth simulation model (IBSNAT, 1986), which had been built into the SIMCOM model, was used to simulate irrigated maize yields for each of the 20 years. The maize price scenario developed by Meiring (1994), was used to obtain stochastic maize prices. The @RISK program was used to generate 20 random maize prices. Each maize price was randomly assigned to different weather years.

An enterprise budget for irrigated maize was constructed with the help of farmers and farm advisers in the area. Production cost (PC) for irrigation maize was calculated at R1 198/ha. Yield variable cost (YC) was calculated at R54,78 per harvesting hour and R0,154/ton/km over a distance of 30 km from the farm to the market.

AGRICO Machinery (PTY.) LTD. supplied the specifications for a 50 ha centre pivot irrigation system with an application capacity of 135 $m^3$/h. The analyses were repeated for an irrigation system with a higher application capacity. For this purpose, the pump and design specifications of the irrigation system were changed to allow it to apply 200 $m^3$/h. The variable cost of applying irrigation water was calculated by using the IRRCOST computer program (Meiring and Oosthuizen, 1992). The variable cost of applying one millimetre of water per hectare for the centre pivot irrigation systems is 64 cent per millimetre.

A 1 050 mm deep Hutton/Deverton soil and a 800 mm deep Avalon/Bergville soil were identified by the Grain Crops Institute for Agricultural Research at Cedara as two fairly representative soil types in the Winterton area. The plant available water capacity for the two soils was 77 and 138 mm respectively.

Two load management scenarios were constructed. The first scenario assumes no interruptions; *e.g.*, the irrigation farmer can apply irrigation water 24 hours every day of the week (168 hours per week). The second scenario assumes that irrigation farmers limit pumping to 81 hours per week. This scenario is closely related to ESKOM'S Ruraflex load management programme. Ruraflex enables irrigation farmers to obtain cheaper electricity if pumping is restricted to the off-peak periods. In Ruraflex the total off-peak periods per week amount to 81 hours (about 12 hours per day).

The SIMCOM model was used to search over alternative combinations of depletion levels to find an irrigation-management strategy that maximizes the expected utility for each load management scenario, risk preference, application capacity and soil type. The optimized CDFs-NR, with and without pumping restrictions, were used in the comparisons. The GSD program of Cochran and Raskin (1988) was used to calculate the amount of incentive required by each type of decision maker under all the anticipated management and production conditions.

## 6.5 RESULTS

### 6.5.1 The effects of pumping restrictions on the profitability of irrigation

The average per hectare reductions in the net returns from irrigated maize produced in the Winterton area, and the soil-water depletion levels at which irrigation was initiated for the two load management scenarios on the Hutton and Avalon soils when pumping capacities were 135 $m^3/h$ and 200 $m^3/h$ respectively, are presented in Table 6.1.

Table 6.1 The average per hectare reductions in net returns from irrigated maize and the soil-water depletion levels for two load management scenarios on two soil types with two pumping capacities in the Winterton area

| LOAD MANAGEMENT SCENARIOS | 135 $m^3/h$ | | 200 $m^3/h$ | |
|---|---|---|---|---|
| | Hutton | Avalon | Hutton | Avalon |
| No interruptions (168 hrs/week) | | | | |
| Net income loss (R/ha) | 0 | 0 | 0 | 0 |
| Trigger level (%) | 85 | 81 | 85 | 78 |
| Pumping restrictions (81 hrs/week) | | | | |
| Net income loss (R/ha) | 95 | 136 | 11 | 23 |
| Trigger level (%) | 71 | 68 | 82 | 76 |

Net returns are reduced by between R11/ha and R136/ha when a pumping restriction is introduced. The lowering of the application capacity of the irrigation system and the soil's PESW render irrigation farmers vulnerable to reductions in net returns resulting from pumping restrictions.

Net return losses due to pumping restrictions increase from R95/ha to R136/ha if the PESW is lowered from 138 mm (Hutton) to 77 mm (Avalon). Farmers irrigating a soil with a low PESW (Avalon soil) will thus lose an additional R41/ha, because the soil is not able to store enough water to offset pumping restrictions.

The application capacity of the irrigation system is another important factor affecting the potential impact of pumping restrictions on the net returns generated from irrigated maize. For example, the average reduction in net returns on the Avalon soil decreases by R113/ha from R136/ha to R23/ha if the application capacity of the irrigation system increases from 135 $m^3/h$ to 200 $m^3/h$.

From the results it is clear that the increase in application capacity can partially substitute income losses resulting from pumping restrictions and the irrigation of soils with low PESW.

The soil-water depletion levels (expressed in percentage points) where irrigation is triggered to maximize the expected net returns for maize, vary between 71 and 85 % of PESW. Irrigation water is applied sooner (higher depletion levels) if pumping restrictions are introduced or the soil's PESW is lower. For example, with the 138 mm PESW soil, the 135 $m^3/h$ application capacity and no interruption load management scenario, the optimal irrigation strategy calls for the irrigation of maize when 85 % of the plant extractable soil water is depleted. The trigger level increases to 71 % of PESW if pumping time is restricted. Similarly, the depletion level increases from 85 % for the high PESW soil (Hutton soils) to 81 % if the soil's PESW is lowered (Avalon soil).

Irrigation is however triggered at lower soil-water levels if the application capacity of the irrigation system increases. On the low application capacity system, for example, irrigation water is applied when 71 % of the Hutton soil's PESW is depleted. In comparison, the trigger level decreases to 82 % when the application capacity of the irrigation system increases to 200 $m^3/h$.

The average per hectare maize yields and the amount of irrigation water applied with the two load management scenarios on soils with PESW of 138 mm and 77 mm and application capacities of 135 $m^3/h$ and 200 $m^3/h$ respectively are presented in Table 6.2.

Table 6.2 The average maize yields (ton/ha) and the amount of irrigation water applied (mm/ha) with the two load management scenarios on two soil types and two pumping capacities in the Winterton area

| LOAD MANAGEMENT SCENARIOS | 135 $m^3/h$ | | 200 $m^3/h$ | |
|---|---|---|---|---|
| | Hutton | Avalon | Hutton | Avalon |
| No interruptions (168 hrs/week) | | | | |
| Yield (ton/ha) | 9,72 | 9,66 | 9,71 | 9,68 |
| Water (mm/ha) | 146 | 179 | 147 | 191 |
| Pumping restriction (81 hrs/week) | | | | |
| Yield (ton/ha) | 9,48 | 9,33 | 9,69 | 9,68 |
| Water (mm/ha) | 158 | 190 | 153 | 220 |

The average maize yield declines when a pumping restriction is introduced. However, the decline in maize yield is substantially reduced if the application capacity of the irrigation system is increased from 135 $m^3/h$ to 200 $m^3/h$. For example, the pumping restriction only reduces maize yields by 20 kg/ha on the Hutton soil if the application capacity of the irrigation system is 200 $m^3/h$, compared to the 240 kg/ha reduction in maize yield when the application capacity is 135 $m^3/h$.

In contrast to the decline in the average maize yields, the average amount of irrigation water applied increases when pumping time is restricted. The average amount of irrigation water applied on the Hutton and Avalon soils with an application capacity of 135 $m^3/h$, for example, increases by 12 mm/ha and 11 mm/ha respectively when a pumping restriction is introduced. This is because irrigation is triggered at higher soil-water levels.

The use of pumping restrictions as a policy instrument to restrict the use of irrigation water or to increase the efficiency with which irrigation water is used, will fail. The reason is that it will have the opposite effect because irrigation farmers will be inclined to use more irrigation water.

### 6.5.2 Evaluation of pumping restrictions with non-neutral risk preferences

Both ESKOM and irrigation farmers are concerned with the amount of discount on the cost of electricity that must be offered to keep expected net returns from falling when load management is imposed. The effect of risk preferences on the amount of discount needed to keep irrigation farmers from being left worse off by pumping restrictions, are shown in Table 6.3. The results have been obtained by calculating the amount that must be added to the net returns on irrigation maize when load management is introduced to keep the distribution of net returns obtained under restricted pumping from being stochastically dominated by the unrestricted pumping net income distribution.

The results show that the amount of compensation needed by irrigation farmers if they are not to be left worse off, increases with risk aversion. The risk-seeking decision makers using the 135 $m^3/h$ system on the Hutton soil require a subsidy of R46/ha if a 81 hour per week pumping restriction is introduced. Risk-averse decision makers, on the other hand, require a subsidy of R220/ha. The significant increase in the required subsidy is the result of income losses in drier weather years when insufficient irrigation water is applied due to reduced pumping capacity caused by load management. Because risk-averse decision makers seek to maximize the worst outcomes and disregard the rest of the net income distribution, a much higher incentive must be offered to keep risk-averse irrigation farmers from being left worse off.

Table 6.3 The amount of incentive required (R/ha) to maintain expected utility under pumping restrictions for risk-seeking, risk-neutral and risk-averse decision makers on the Hutton and Avalon soils with application capacities of 135 $m^3/h$ and 200 $m^3/h$ respectively

| SOILS | 135 $m^3/h$ RISK PREFERENCES | | | 200 $m^3/h$ RISK PREFERENCES | | |
|---|---|---|---|---|---|---|
| | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) |
| RESTRICTED PUMPING | | | | | | |
| Hutton soil | 46 | 95 | 220 | 6 | 11 | 25 |
| Avalon soil | 150 | 136 | 282 | 6 | 23 | 54 |

Risk-seeking = absolute risk-aversion coefficients between -0.0003 and -0.00003
Risk-averse = absolute risk-aversion coefficients between -0.00003 and 0.0003

The required subsidies for the three types of decision makers irrigating the Hutton soil are significantly reduced to R6/ha, R11/ha and R25/ha respectively if the application capacity of the irrigation system is increased to 200 $m^3/h$. The amount of subsidy required by risk-averse decision makers, for example, declines by R195/ha from R220/ha to R25/ha because the higher application capacity limits the losses of crop yields in the drier weather years, by offsetting the reduced pumping capacity caused by load management.

## 6.6 CONCLUSION

From the results it is clear that financial incentives must be offered to the irrigation farmers if they are not to be left worse off when load management strategies are introduced. Irrigation farmers must therefore ensure that the per hectare savings in the cost of electricity due to the use of cheaper electricity are at least equal to the amount of subsidy required not to leave them worse off by restricting pumping hours. Clearly the economic profitability, and therefore also the adoption of the proposed Ruraflex load management programme, will be affected by the financial incentive offered (reduction in the cost of electricity), the risk preference of the irrigation farmer, the application capacity of the irrigation system and the soil's PESW, as well as the efficiency with which irrigation farmers can adjust their irrigation-scheduling strategies to the load management programme.

The importance of proper irrigation scheduling will increase under load management conditions. The net returns maximizing strategy calls for initiating irrigation sooner (higher soil-water levels). Failure to adjust the soil-water depletion levels will increase yield losses in the drier weather years. An over-adjustment in the soil water-depletion levels will result in more irrigation water being applied. This can lead to the use of more electricity (longer pumping hours), eventually offsetting the possible advantages of using the cheaper electricity offered under the load management programme.

The finding of this research is that load management programmes can potentially increase the economic efficiency of irrigation farming because there is a wide variation in the amount of subsidy required to keep irrigation farmers from being left worse off by load management programmes; especially, if it is made voluntary. Some irrigation farmers would however be better off if they do not participate in load management programmes, because of low application capacities of irrigation systems, poor quality soils, high risk aversion and/or the inability to adjust irrigation management to load management programmes.

Further research is required to determine the effect of different climates, soil types, irrigation systems and crop rotations on the amount of incentive needed to compensate irrigation farmers for restricted pumping hours.

In addition, further research should focus on the tradeoffs between the reduced risk of income losses and the capital outlay needed for increasing the application capacity of irrigation systems.

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# SUMMARY OF VOLUME II

JHF Botes and LK Oosthuizen

## INTRODUCTION

The focus of this research was to value irrigation information by accounting for all the uncertainties of making real-time irrigation scheduling decisions on an annual basis using simulation and optimization. Risk is an important aspect in agricultural production and, therefore, risk preferences need to be explicitly accounted for when valuing information. Major sources of risk for irrigation farmers in the Winterton area are changes in input and output prices, variable weather conditions and variability in irrigation water supplies. Better information enables farmers to make more relevant and timely production decisions. Consequently, better information can improve the farmer's ability to manage risk. However, *it is important that farmers should be informed about the economic value of better* information, because information is valued differently by farmers with different risk preferences, farming systems and production conditions.

Irrigation farmers in the Winterton area, farming under conditions of variable water supply and production conditions, are uncertain about the value of better irrigation information. The uncertainty concerning the value of more sophisticated irrigation information caused irrigation farmers to be hesitant in adopting better-information strategies. The difficulty of systematically searching through alternative irrigation scheduling rules under uncertainty to find the optimum, especially under limited water supply conditions, restricted agricultural economists from readily determining the amount irrigation farmers would be willing to pay for obtaining better irrigation information.

The main objective of this research was to determine the amount irrigation farmers with non-neutral risk preferences, farming in the Winterton area under conditions of unlimited and limited water supplies, would be willing to pay for obtaining better irrigation information if production conditions and product prices are uncertain.

Other objectives were the following:

1) To formulate representative farms for the Winterton area.

2) To determine to what extent the value of irrigation information is affected by type and quality of information, the availability of irrigation water, the soil's plant extractable soil water (PESW), the size of the absolute risk-aversion coefficients (RAC) and the correlation between weather years (yields) and product prices.
3) To determine to what extent information levels and risk attitudes affect the optimal decision rules for initiating irrigation under conditions of unlimited and limited water supply on two soils with different PESW.
4) To develop a simulation optimization approach for the optimization of management decisions under dynamic plant-growth conditions.
5) To elicit RACs for irrigation farmers in the Winterton area that are a realistic reflection of their risk preferences towards annual income and wealth risk.
6) To adjust validation techniques used for crop models to specifically recognize the dynamic and uncertain environment in which crop production takes place, as well as the importance of the decision maker.
7) To determine the effects of pumping restrictions on irrigation efficiency.

This section of the report consists of an introduction, six chapters addressing relevant questions about the value of irrigation information and pumping restrictions and a summary. All the chapters comprise an introduction, conceptual model, empirical model, results and implications for further research.

The research begins with Chapter 1 in which representative farms are formulated for the research area. In Chapter 2, two crop models commonly in use in South Africa are assessed in terms of their ability to analyze the economics of crop production correctly. In Chapter 3 the simulation optimization model (SIMCOM) is developed and applied to determine the amount risk-neutral decision makers in the Winterton area would be willing to pay for better irrigation information. Risk preferences for irrigation farmers in the Winterton area are presented in Chapter 4. The amounts irrigation farmers with varying risk preferences would be willing to pay for more sophisticated soil-water, plant-growth and weather information, are estimated in Chapter 5. In the last chapter of this section, the effects of pumping restrictions on irrigation efficiency are determined.

## DATA COLLECTION

Data used in this research were collected by means of questionnaires, group discussions and expert opinions. However, the greater part of the data was generated by using a simulation approach.

First, a questionnaire was administered, identifying the farmers' attitudes, perceptions and management responses to variability. In addition, socioeconomic information was obtained including data concerning the farmers' financial situation, biographical data, and the type of farming arrangement, as well as information about the farming operation, such as enterprise selection, cultivated hectares and irrigation equipment.

The socioeconomic information obtained by means of the questionnaire, along with expert opinions, was used to construct representative irrigation farms and identify farmers that could take part in group discussions to construct enterprise budgets. Enterprise budgets for all the major crop and livestock enterprises in the Winterton area were constructed by holding group discussions with farmer groups and agricultural advisors.

Two other questionnaires were administered in the area. The first questionnaire was mailed to all the irrigation farmers, asking them to formulate an irrigation-scheduling strategy for maize that used very little or no-soil-water, plant-growth and weather information for unlimited and limited water supply conditions, respectively. An irrigation scheduling expert in the area was employed, along with the questionnaire responses, to formulate no-information irrigation-scheduling strategies.

The second questionnaire was administered personally to 53 irrigation farmers. This questionnaire was used to elicit risk preferences towards annual income and wealth risk on three income/wealth levels, respectively.

A data set, consisting of 139 data points, collected at 14 different locations across South Africa, was obtained from various institutions. The experimental data together with historical weather data sets for each location, were used to validate two commonly used crop-growth simulation models.

All the data obtained from irrigation farmers in the Winterton area together with 20 years' historical weather data were used as input into a simulation and optimization model. The model generated cumulative distributions of before-tax net returns (CDF-BTNI) at farm level for each of two soil types, three different risk preferences, six irrigation-information strategies and two water availability scenarios. In addition, CDF-BTNI was optimized to determine how sensitive the value of information was to changes in RACs and the correlation between weather years and product prices. In total more that 400 simulation and optimization runs were used to generate the data analyzed in this research.

## THE RESEARCH AREA

The Winterton area in Western Natal was selected for this research because of the periodic irrigation water shortages in the Little Tugela and other river systems. In addition, much work has already been done in respect of researching and introducing more sophisticated irrigation-information strategies into the area.

The research area extends over approximately 7 000 hectares of irrigation land and belongs to about 100 land owners. However, due to the uncertainty concerning the availability of irrigation water, only 5 192 ha are currently irrigated. It is, therefore, not surprising that farmers indicated that uncertainty concerning the availability of irrigation water is one of the major sources of risk in the area. Other important sources of risk identified by farmers in the area are changes in input and output prices, variability in the weather, inflation and political changes. Irrigation farmers regard the introduction of irrigation as a very important way of managing these sources of risk. Other ways in which irrigation farmers are trying to manage risk are diversifying farming enterprises, keeping enough feed reserves (fodder bank) and scheduling irrigation water.

The characteristics of irrigated farms in the Winterton area are very diverse. The average farm size is, for example, 613 ha with a standard deviation of 1 048 ha. The number of hectares under irrigation varies between 10 and 320 ha, land used for dry-land crop production varies between zero and 730 ha, and land used for grazing varies between zero and 1 500 ha. Irrigation is used on about 47 % of the cultivated lands.

The predominant irrigation system is centre pivots, which irrigate about 63 % of the land under irrigation. Drag line irrigation systems are very commonly used for the irrigation of pastures. Drag line systems irrigate about 26 % of the land under irrigation.

A total of nine representative farms were identified in the Winterton area. The representative irrigation farms were categorized into three groups, depending on the size of their irrigation enterprises. The first group (four in total) has irrigation enterprises of about 50 ha each which are combined with different pasture and dry-land production systems. The second type of representative farm has 100 ha under irrigation, 60 ha of which are irrigated by centre pivot and the remainder by drag lines. This type of farm has no grazing or dry-land enterprises in addition to the irrigation. The third group of representative irrigation farms has about 200 ha under irrigation, 170 ha of which are irrigated by centre pivots and the remainder by drag lines. Irrigation enterprises are combined with different combinations of grazing and dry-land production systems.

The representative farm used in this research has 200 ha under irrigation and consists of an additional 50 ha dry-land and 300 ha grazing. Of the 200 ha under irrigation, 130 ha are used to cultivate cash crops, and the remainder (30 ha) is used to irrigate pastures. Production enterprises are beef, dry-land and irrigated maize.

Avalon and Hutton soils with PESW of 77 and 138 mm respectively were identified as the two representative soil types used for cash crop production. Unlimited and limited soil water availability scenarios were formulated. The scenario used to describe the limited water supply condition was a 50 % reduction in the amount of water used by the no-information irrigation strategy under normal production conditions. The no-information strategy normally applies between 280 and 320 mm irrigation water per hectare effectively. Consequently, the amount of irrigation water available under limited water supply conditions was limited to 150 mm. The unlimited water supply scenario placed no limitation on the amount of irrigation water applied.

## THE FORMULATION OF REPRESENTATIVE FARMS IN THE WINTERTON IRRIGATION AREA

Representative farms (RFs) have often been used in local agricultural-economic research. This has resulted in an analysis of the use of RFs in agricultural-economic research and the development of a procedure for general use. This procedure was developed by formulating a well-motivated definition and structuring the procedure systematically according to this definition. The constant use of this procedure means that RFs from different studies can be compared to each other.

The concept of typical farms has been used in research even since the twenties. This research was done in many fields, including problems on both macro- and micro levels. During the development of the typical farm concept it became clear that it should be seen as a modal rather than an average concept. In local studies a typical farm has been defined as the most common type of farm situation found in a homogeneous geographic area, or which will be applicable to a certain group of farmers in an area. In the formulation of RFs various physical and financial variables can be used to distinguish between different RFs. These variables however, should be limited. The objective with the RFs will be a determining factor in their composition, while the best method for obtaining data will be determined by the reliability of the data required.

The objective with the formulation of RFs for the Winterton area was to determine the value of irrigation information for decision makers under risk. It is therefore obvious that the RFs should include as large a number of farms as possible in order that the results obtained from the analyses could be applicable to as many farms as possible.

Consequently a RF was defined as a resource situation with which a reasonable number of farmers could associate themselves and which differed from other resource situations to such an extent that these differences could be expected to result in different economic and financial situations. Based on this definition a four-step procedure was followed to identify RFs for the region. In the first step the fixed-resource situation was identified. The second step comprised the determination of the nature and scope of the variable-resource situation. The analysis of a typical liability structure for the region was done in the third step. In the final step management strategies were identified for every RF.

A questionnaire containing thirteen questions was formulated to determine the fixed-resource situation in the region. It was completed by 53 irrigation farmers in the Winterton area by means of personal interviews. Fifty of the questionnaires, which constituted 94 % of the farmers, could be used. Statistical analyses of the data were done by computer and frequency distributions were drawn up. The irrigation surface, dry-lands and pastures, as well as the type of irrigation and livestock, were used as variables in the identification of nine fixed-resource situations.

Data concerning the variable-resource situation, which was dependent on the fixed-resource situation, were obtained by means of group discussions with producers in the region. A questionnaire was used as basis and data concerning crops, livestock, labour type and number of implements, and the technical and economic coefficients of the mechanization system were obtained too.

For the identification of the typical capital structure of farmers in the area, questionnaires concerning the socioeconomic aspects of farms in the area were completed. In addition, anonymous balance-sheet information was obtained from the co-operative. Frequency distributions were compiled and from these two typical debt:asset ratios were identified.

In the group discussions concerning the variable-resource situation farmers had to indicate the most important crops, cultivated pastures, as well as the types of livestock. They also had to indicate management decisions with respect to the above, *i.e.* crop-rotation systems, utilization of cultivated pastures and general practices concerning livestock enterprises.

The above-mentioned procedure resulted in the identification of nine RFs for the Winterton irrigation area. On four of the RFs 50 ha were irrigated, on one of them the figure was 100 ha and on four more it accounted to 200 ha. Where 50 ha were irrigated, 0 to 150 ha dry-lands were found and 0 to 300 ha natural veld. The irrigated surfaces were used for the cultivation of pastures under drag line systems which was utilized by dairy as well as beef cattle. On the dry-lands maize is grown, and the natural veld is used for beef cattle. The RF with 100 ha irrigation has no dry-lands or natural veld. Sixty hectares centre pivot and 40 ha with drag line systems. Cash crops including maize, wheat and soybeans are cultivated under centre pivot irrigation, while the drag lines are used for cultivated pastures which is utilized by a dairy herd. In combination with the 200 ha irrigation, 0 to 50 ha dry-lands and 0 to 300 ha natural veld are included. Of the 200 ha, 170 ha are under centre pivot irrigation, whereas the rest is irrigated by means of drag lines. The cultivation and utilization of the irrigated crops as well as the natural veld were similar to the situations discussed earlier.

The typical farms with 50 ha irrigation and no dry-lands usually need 19 implements with a market value of R123 100, while the 50 ha irrigation in combination with 150 ha dry-lands typically need 31 implements with a market value of R230 400. For irrigation surfaces of 100 and 200 ha respectively, 36 and 38 implements with a market value of R380 400 and R384 400 are needed. The number of labourers employed on irrigation surfaces of 50, 100 and 200 ha are 20, 20 and 30.

Farmers can be divided into two groups on the basis of their capital structure, namely farmers with debt:asset ratios of 5 % and 40 %. Total liabilities are composed of 50 % long-term, 10 % medium-term and 40 % short-term liabilities. Bank overdrafts comprise 30 % short-term liabilities and monthly co-operative accounts 70 %.

Present management practices include a mono culture crop-rotation system of maize, wheat and soybeans under centre pivot irrigation. The 300 ha natural veld is grazed by a 100 cow beef cattle enterprise. Included in all the typical farms is a dairy herd of 100-cows-in-milk. Surplus cultivated pastures and maize crop residue are used to fatten speculation cattle. These cattle are considered to be additional to the beef cattle enterprise.

The four step procedure for the formulation of RFs can only be applied after the RFs have been defined. This procedure makes it possible to compare RFs from different studies with each other. By using this procedure, typical farms were identified for the Winterton irrigation area according to their fixed- and variable-resource situations. A typical capital structure and management practices were also identified for the region. This created the facility to compare different management practices with each other and to evaluate management strategies economically. The results obtained in this way allow for wider application possibilities than results obtained by means of case studies or average values.

## USE OF THE PUTU IRRIGATION AND IBSNAT CROP MODELS FOR ANALYZING THE ECONOMICS OF CROP PRODUCTION

Crop-simulation models should be used to determine yield responses to different irrigation-information strategies, because crop yields are affected by the amount as well as the timing of irrigation water applications. Although it is questionable whether crop-simulation models can in fact be proven fully representative and valid, validation in relative terms (relative to the obtained data or research problem) is important to ensure the credibility of research results.

The main objectives of this chapter were to adjust validation techniques used for crop-simulation models to specifically account for the dynamic and uncertain environment in which crop production takes place, as well as the important role the decision maker plays in analyzing and interpreting results generated by simulation models.

Other objectives were the following:

1) To assess the validity of the IBSNAT crop-growth simulation and the PUTU crop-yield simulation (called PUTU irrigation) models in terms of their ability to analyze the economics of crop production under diverse production conditions in South Africa.
2) To determine whether the errors made by the crop-simulation models would be more important to risk-seeking, risk-neutral or risk-averse decision makers.

Assessment of model validity and the selection of a credible simulation model largely depend on the nature of the problem under investigation, the characteristics of the simulation model and the characteristics of the system under investigation. However, these are not the only factors influencing the selection of simulation models. Model selection can also be influenced by factors such as computer language and hardware incompatibilities, user friendliness and the researcher's access to simulation models.

A general procedure for assessing the validity of simulation models was identified. The validation procedure combines the critical factors influencing model selection with specific steps in the model development process. This procedure was adjusted specifically to account for the fact that the economics of crop production analyzes the cumulative distribution functions of net returns (CDF-NR) generated by alternative production and/or management strategies.

The first step was to identify the nature of the problem under investigation. Deductive reasoning was used predominantly to identify the important characteristics affecting the economics of crop production. More specifically, deductive reasoning entails the identification of critical output variables that need to be analyzed, the determination of important interrelationships between the output variables, and the identification of precise performance targets.

The second step was to examine the simulation model's conceptual structure. A simulation model must be selected so that its characteristics suit the nature of the problem under investigation. A combination of deductive and inductive reasoning can be used to determine whether the simulation model is capable and sensitive enough to simulate the important output variables as indicated by the characteristics of the problem under investigation.

The IBSNAT crop-growth and PUTU irrigation models were validated for analyzing the economics of crop production under diverse production and management conditions in South Africa. Maize, wheat and soybean data, consisting of 139 data points from 14 locations across South Africa, were collected and used in the validation. The experimental data were collected over a wide range of production and weather conditions. The actual net returns generated at the experimental sites were compared to the net returns calculated for the simulated results. The statistical analyses were done according to the guidelines and array of statistics described by Willmott.

The ability of the IBSNAT and PUTU irrigation models to account for different climatic conditions, as well as cultivar and management differences, such as changes in plant population, planting dates and row widths, was intrinsically addressed. From the analysis it was apparent that the PUTU irrigation model is not very sensitive to changes in management practices, such as plant populations, row spacing and cultivars.

It is important to determine whether the differences in the conceptual models of the simulation models validated are significant in terms of the specific research objectives. The IBSNAT crop-growth simulation models (CERES maize and CERES wheat) were compared to their counterparts the PUTU crop-growth simulation models (PUTU maize and PUTU wheat). The differences in the conceptual models were insignificant in terms of the stated research problem, because both model groups were simulating crop growth by using very similar conceptual models. The accuracy of these predictions depended solely on the genetic coefficients selected. Genetic coefficients were not always scientifically determined. Consequently, genetic coefficients could be manipulated easily to simulate actual yields as well as the actual net returns (NRs) for a small data set accurately. It was decided not to include the PUTU crop-growth models (PUTU maize and PUTU wheat) in the analysis. The reasons were that the differences in the conceptual models were very technical. In addition, the accuracy of the two model groups depended completely on the correctness of the genetic coefficients selected.

The third step was to determine whether the model's output data were sufficiently accurate for the model's intended use. Both the IBSNAT and PUTU irrigation models proved acceptable for analyzing the economics of maize production. Further validation work needs to be done on both the PUTU irrigation and the IBSNAT crop-growth models for wheat and soybeans, because the systematic errors obtained indicated that simulation accuracy can be improved substantially. In this regard, it is the PUTU irrigation model in particular that shows promise, because it requires less input. The inputs are also more readily available. In addition, the IBSNAT model seems to be very sensitive to the correct model parameter specifications. Many of these parameters, especially for crops other than maize and wheat, have not been adjusted for South African cultivars, soils and climatic conditions. Another reason why the wheat and soybean models did not perform as well as the maize models might be that not enough wheat and soybean data points were available under conditions of moderate to high stress.

The risk preferences of decision makers need to be taken into consideration, especially when crop models are calibrated or adjusted to specific production conditions. The amount by which each value in the simulated CDF-NR should be adjusted in order to no longer dominate (or be dominated by) the actual CDF-NR, varies substantially if risk attitudes change, but does not seem to follow a predictable pattern, *e.g.*, always higher for risk averters compared to risk seekers. It was also clear that risk preferences of the decision makers might also influence the selection of crop models.

It was concluded that both the maize models of IBSNAT and PUTU irrigation are suitable for analyzing the economics of crop production under diverse conditions in South Africa. The wheat and soybean models show promise, but need further work to improve their accuracy.

## A SIMULATION OPTIMIZING APPROACH FOR EVALUATING INFORMATION FOR CROPS UNDER LIMITED WATER SUPPLY

Although crop models can reproduce the dynamic irrigation environment, they must be linked with an efficient search optimizer, economic and irrigation components before the value of irrigation information can be estimated.

The main objective of Chapter 3 was to develop a simulation and optimization approach which can be used to value irrigation information under risk for decision makers with risk-neutral risk preferences.

Other objectives were the following:

1) To estimate the value of irrigation information under conditions of unlimited and limited water supply for risk-neutral decision makers.
2) To determine to what extent PESW and the availability of irrigation water affect the value of information.
3) To determine the sensitivity of the value of information to assumptions made about the correlation between weather years (yield) and output prices.

A simulation and optimization approach was developed through a series of links between a biological crop-growth model, irrigation and economic components and an external optimization procedure. The maize crop-growth simulation model used by IBSNAT (CERES maize), which was tested and validated in Chapter 2, was used. Economic and irrigation components were developed and coded into the CERES model to enable the scheduling of irrigation water, given the specific irrigation information used and the decision rule for initiating irrigation. The simulated yields and irrigation water amounts were then used to calculate the BTNI for specific weather years, production conditions, information strategies and the decision rule for initiating irrigation. Finally, the crop growth, irrigation and economic components were linked with the external optimizer to determine the optimum decision rule for initiating irrigation for each information strategy.

The complex search procedure used based the search on neither first-order nor second-order derivatives, but used a geometric figure to move along the response surface in search of an optimum. Four basic operations, namely reflection, expansion, contraction and shrinkage could be used to conform the simplex to the characteristics of the response surface.

Six alternative irrigation-information strategies which used different types and quality of soil-water, plant-growth and weather information were constructed. Irrigation-Information Strategy 1 was used as a benchmark strategy with which the more sophisticated irrigation-information strategies were compared. The no-information strategy uses no formal measuring method to determine when to irrigate. Irrigation scheduling is based on experience of rising water demand as crop growth progresses through the growth season.

Irrigation-Information Strategy 2 used intermediate weather and soil-water information. Daily potential evaporation figures obtained from an evaporation pan are used to calculate the daily soil water loss. A check is kept on the amount of water in the soil by subtracting the daily calculated evapotranspiration and adding rainfall. Once a week the soil-water levels are corrected to the nearest 10 mm of the actual soil water content.

Strategy 3 provided irrigation farmers with intermediate soil-water information only, assuming that daily soil-water levels could not be measured accurately due to measurement and sampling errors. Soil water estimation errors were assumed to be uniformly and randomly distributed and not greater than 15 % of the PESW. However, the intermediate soil-water information provided by Strategy 3 is more sophisticated than the intermediate soil-water information provided by Information Strategy 2.

Irrigation-Information Strategies 4, 5 and 6 used, respectively, perfect daily soil-water information alone, perfect soil-water combined with intermediate plant-growth and future rainfall information, and perfect soil-water combined with perfect plant-growth and future rainfall and ET information.

Product prices for maize and beef were stochastically varied. A correlation coefficient of 0,3219 was used in the @RISK program to generate 20 sets of correlated maize and beef prices. Each set of output prices was randomly assigned to 20 sets of meteorological data obtained for the Winterton area. A sensitivity analysis was done on the value of information by assuming a perfect negative correlation between weather years and product prices.

The SIMCOM model was programmed to maximize the expected value of the before-tax net income distribution (EV(BTNI)) generated by each information strategy. The NR for the irrigated maize enterprise was first calculated by using the simulated yield and water amount for a specific weather year. The NR generated by the beef and dry-land maize enterprises for the same weather year was added and overhead cost was deducted. The procedure repeated itself for all 20 weather years. Equal probabilities were assigned to the BTNI values and the EV(BTNI) for that specific set of decision variables was obtained. A next set of trigger levels in three different plant-growth stages was calculated and introduced into the SIMCOM model. The EV(BTNI) was similarly calculated and compared to the EV(BTNI) obtained for the first set of decision variables.

The results showed that information was a partial substitute for land quality and the availability of irrigation water. Information strategies using more sophisticated information succeeded in limiting the reduction in expected net returns when the soil quality in terms of PESW dropped or the availability of irrigation water was restricted.

It was found that the use of more sophisticated irrigation information improved the irrigation farmer's ability to adjust the timing or scheduling of irrigation water. As a result, more sophisticated irrigation information increased the expected net returns due to the attainment of near maximum yields with savings in the amount of irrigation water applied.

Risk-neutral irrigation farmers proved willing to pay R136/ha and R173/ha for better irrigation information under unlimited water supply conditions on Hutton and Avalon soils, respectively. Consequently, irrigation farmers would be willing to pay about 27 % more for information if they were irrigating Avalon soil (lower PESW).

The value of better irrigation information was found to increase to between R202/ha and R331/ha, respectively, for the Hutton and Avalon soil types if irrigation water was limited. The difference in the amount farmers could pay for better irrigation information increased by 49 and 91 % on the two soils respectively, if irrigation water became limited.

Diminishing returns to better irrigation information were clearly demonstrated by the results. On Avalon soil, with limited water supply, for example, the checkbook strategy (2) accounted for 70 % of the increase in the expected return generated by Information

Strategy 5. Strategy 3 accounted for 96 %, while Strategy 4 resulted in an additional 0,5 % increase only. The increase in the expected net return declined by 2,5 % when future ET information was added to the future rainfall and perfect soil-water information already used by Information Strategy 5.

Soil-water information accounted for a large proportion (between 97 and 99 %) of the increase in expected return due to the use of better irrigation information. Therefore, it may be assumed that irrigation farmers would rather invest in better soil-water information than in future weather information.

The value of information for risk-neutral decision makers was found to be not very sensitive to the assumptions about correlation between weather years and product prices.

It was concluded that the SIMCOM model could be used effectively to calculate the increase in expected returns due to the use of more sophisticated irrigation information. Risk preferences of decision makers, however, should also be incorporated into the analyses.

## ELICITATION OF RISK PREFERENCES FOR IRRIGATION FARMERS IN THE WINTERTON AREA: WEALTH RISK VERSUS ANNUAL INCOME RISK

Any analysis of risky decisions should account for the risk preferences of decision makers. Irrigation farmers in the Winterton area are faced with long- and short-term decisions that could significantly affect their well-being (annual income or wealth).

Risk preferences towards uncertain wealth have not yet been elicited in the area. In addition, risk preferences towards uncertain short-term income for irrigation farmers in the Winterton area have not yet been determined. Consequently, there is a lack of empirical evidence to guide the selection of RACs which can be used to determine the value of better irrigation information for decision makers with non-neutral risk preferences.

The main objective of Chapter 4 was to determine whether attitudes towards wealth risk were significantly different from attitudes towards annual income risk.

Other objectives were the following:

1) To obtain RACs for use in farm-level analyses concerning annual income and wealth risk.

2) *To determine whether decision makers will exhibit decreasing absolute risk aversion* as the level of annual income and wealth increases.

3) To test whether the consistency with which risk preferences were measured differed significantly when the level of the outcome measure (income or wealth) increased, or when wealth instead of annual income was used as the performance measure.

The interval approach was used to elicit risk attitudes towards both annual income and wealth risk. The risk-elicitation measurement scales used in the USA by Tauer were slightly adjusted and rescaled for use under South African conditions.

The annual income performance measure was identified as the before-tax net income farmers in the Winterton area would generally expect. From financial data and information supplied by experts in the area it was established that three representative annual income levels were R0, R60 000 and R120 000. Wealth was expressed as the net present value (NPV) of returns from an irrigation investment over 15 years. The 15-year NPV of R250 000, R600 000 and R950 000 were selected from calculations made by Meiring and Oosthuizen.

A questionnaire was drawn up for distributions generated by the INTID computer program. The elicitation was repeated for each of the selected annual income and wealth levels to test for consistency of risk preferences.

The questionnaire was administered to 53 irrigation farmers in the Winterton area. Fifty-seven and 62 % respectively of the irrigation farmers proved to be consistent at all three the annual income and wealth levels. Only 38 % of the farmers were consistent at all six of the annual income and wealth levels.

The results indicated that risk preferences towards wealth differ significantly from risk attitudes towards annual income. Decision makers became more risk averse when wealth instead of annual income was at stake. Consequently, rescaling of RACs elicited on an annual income basis for use in long-term risk studies might lead to the misrepresentation of decision makers' willingness to assume risk.

Most of the annual income RACs (99 %) varied between -0,0001 and +0,001. However, almost 32 % of the irrigation farmers could be placed in a risk interval around risk neutrality (-0,00003 to 0,0001). Fifty-one per cent of the consistent decision makers could be placed on the risk-seeking end of the measurement scale, with the remaining 17 % on the risk-averse end of the measurement scale.

Decision makers were inclined to take on more risk at the very low BTNI level (R0), than they normally would at higher monetary outcomes. This resulted in a relatively strong risk-seeking behaviour expressed around the R0 BTNI level, compared to the other two BTNI levels. However, apart from the statistical significant increase in risk aversion between BTNI levels 1 vs 2 and 1 vs 3, risk preferences did not show statistically significant increases or decreases as the levels of income/wealth increased.

Little evidence was found that decision makers displayed decreasing absolute risk aversion as the level of wealth increased.

The number of consistent decision makers (*e.g.*, decision makers that were within two RAC intervals on either side from where they were placed the first time, if the elicitation was repeated) increased from 77 % at BTNI level 1 to 81 and 90 % at BTNI levels 2 and 3. A very similar consistency pattern repeated itself with the wealth elicitations, where 71 % of the decision makers were consistent on the first wealth level. The passing rate increased to 85 and 98 % at wealth levels 2 and 3.

Care was taken to control for rescaling effects. However, additional care should be taken to control better for a uniform income-to-wealth rescaling factor. The influence of the rescaling factor should be researched further by using three different income-to-wealth rescaling factors, or selecting the income and wealth levels in such a way that the rescaling factor is the same at all three income and wealth levels.

It was concluded that the annual income risk-aversion coefficient elicited for irrigation farmers in the Winterton area can be used in the SIMCOM model to optimize expected utility for the different irrigation-information strategies.

## THE VALUE OF IRRIGATION INFORMATION FOR DECISION MAKERS WITH NON-NEUTRAL RISK PREFERENCES UNDER CONDITIONS OF UNLIMITED AND LIMITED WATER SUPPLY

It is important to consider the risk attitudes of irrigators when assessing the value of information, because strategies which maximize expected profit do not necessarily maximize expected utility. The amount non-neutral decision makers would be willing to pay for better information could, consequently, deviate substantially from the amount risk-neutral decision makers would be willing to pay.

The value of better irrigation information for decision makers with non-neutral risk preferences under conditions of unlimited and limited water supply has not yet been determined.

The main objective of Chapter 5 was to use a comprehensive dynamic approach to determine what irrigation farmers with non-neutral risk preferences would pay to ascertain more sophisticated soil-water, plant-growth and weather information under conditions of unlimited and limited water supply.

Other objectives were the following:

1) To evaluate to what extent factors such as the availability of irrigation water and the amount of PESW influence the value of irrigation information for decision makers with non-neutral risk preferences.
2) To evaluate to what extent changes in RACs affect the value of irrigation information.
3) To evaluate the effect of perfectly negatively correlated yield and product prices on the value of information.

The simulation and optimization approach developed and demonstrated in Chapter 3, together with the six irrigation-information strategies, the representative farm, the selected soil types and water availability scenarios, was used to assess irrigation information for non-neutral decision makers.

The SIMCOM model, however, was adjusted from maximizing the expected value of a random BTNI distribution (Chapter 3) to maximizing expected utility. An exponential utility function was used to account for decision makers with non-neutral risk preferences.

The RAC elicited in Chapter 4 was used to represent risk-seeking and risk-averse risk preferences. A RAC value of -0,0001 was selected to represent risk-seeking preferences, while a RAC value of 0,0001 was selected to represent risk-averse preferences.

A correlation coefficient of 0,321 was calculated and used in the @RISK program along with the maize and beef price scenarios to generate 20 correlated maize and beef prices. Each set of output prices was randomly assigned to the different weather year.

A sensitivity analysis was done to determine whether perfectly negatively correlated yield and product prices affect the value of irrigation information for non-neutral decision makers.

The maximum amount irrigation farmers with unlimited irrigation water supply on Hutton soil (high PESW) would be willing to pay for the highest level of information varied between R136/ha and R330/ha depending on their risk preferences.

Critical variables affecting the value of better irrigation information proved to be the risk preference of the decision makers, the soil's PESW and the availability of irrigation water.

The value of better irrigation information increased if irrigation water was limited or the soil's PESW was lowered. The value of information increased by at least 49 % if irrigation water became limited. Similarly, the value of better irrigation information increased by at least 27 % if the soil's PESW was lowered (Avalon soil). From the result it is clear that information is a partial substitute for soil quality in terms of PESW and the availability of irrigation water.

Risk-averse irrigation farmers farming with unlimited irrigation water supply would be willing to pay about 130 % more for better irrigation information than risk-seeking decision makers. However, with limited irrigation water supplies, especially on Avalon soil, the opposite was true. Risk-seeking irrigation farmers were willing to pay about 67 % more for better irrigation information than risk-averse decision makers.

The amount irrigation farmers would be willing to pay for better irrigation information increased at a diminishing rate as the type and quality of the soil-water, plant-growth and weather information increased.

Soil-water information accounted for at least 94 % of the value of better irrigation information realized with unlimited irrigation water. However, the ability of perfect soil-water information to account for the total value of better irrigation information dropped to about 64 %, if irrigation water was limited.

The type and amount of irrigation information and risk attitudes affected the expected yields and water amounts differently, depending on the availability of irrigation water. Both yields and water amounts increased as risk preferences changed from risk-seeking to risk-averse if irrigation water was not limited. Yields and irrigation water amount were more variable and the effects of risk preferences less visible if irrigation water was limited.

The value of irrigation information was not sensitive to changes in the RACs. A 50 % reduction in the RACs resulted in a maximum decrease of 8 % in the value of information.

No clear relationship between the value of information and assumptions made about the correlation between yield and product prices could be found.

## THE EFFECTS OF PUMPING RESTRICTIONS ON IRRIGATION EFFICIENCY: IMPLICATIONS FOR ESKOM'S TIME-OF-USE ELECTRICITY SUPPLY TO RURAL AREAS

Any economic analysis of pumping restrictions should account for factors such as the soil's plant extractable soil water (PESW), the pumping capacity of the irrigation system, the irrigation farmers' risk preference and the adjustment of irrigation-scheduling strategies.

There is uncertainty about the amount of incentive (cheaper electricity rates) which must be offered to irrigation farmers so that pumping restrictions caused by load management do not make them worse off.

The main objective of Chapter 6 was to use a comprehensive dynamic approach to determine the amount of incentive required by irrigation farmers with non-neutral risk preferences to keep them from being made worse off by pumping restrictions.

Other objectives were the following:

1) To supply background information on the Ruraflex electricity option;
2) To determine how pumping restrictions affected the expected net returns, yields, the amount of irrigation water applied and the irrigation management of maize produced in the Winterton area;
3) To determine how factors like the soil's PESW and the application capacity of the irrigation system influenced the amount of incentive required by decision makers with non-neutral risk preferences.

The electricity tariffs applicable to farm purposes included tariffs A, E, F and D as well as option Ruraflex. An option refers to a possible tariff that is in a test phase and has therefore not yet been proclaimed. Tariff D and Ruraflex are intended for rural users and the other tariffs for larger users. Ruraflex differs from the regular electricity tariffs in that electricity is cheaper during certain periods of the day. ESKOM therefore developed Ruraflex with the intent to supply cheaper electricity to farmers and to shift the electricity use towards periods during which the cost of generation is not so high.

Ruraflex's components can be classified into two categories. The fist category consists of variables put forward as requirements for using the tariff. Thus a user is given the opportunity to decide whether Ruraflex is applicable and if he qualifies to use it. These variables do not necessarily result in a cost implication for Ruraflex, but allows the consumer to save by making the decision that suits his situation best.

There is, however, a cost implication involved with the second group of components. Two groups of cost components have been identified. The first group of cost components affects fixed electricity costs which must be paid, whether electricity has been used or not. These components consist of a basic charge that covers the costs of personnel and the monthly rent that provides for the construction costs. The variable cost components consist of active energy, reactive energy and transmission charges, as well as a voltage discount. Another component that makes Ruraflex an exception to other electricity tariffs is the period concerned. This results in cheaper electricity during certain periods of the day which in turn helps the user to save on the cost of electricity. It is important to notice that all the above-mentioned variable cost components are directly or indirectly dependent on the kilowatt-hours used.

The SIMCOM model developed by Botes was adjusted to optimize expected utility as the principal-performance measure for each load management scenario, risk preference, application capacity and soil type using 20 years weather data from the Winterton area.

Absolute risk-aversion coefficients (RACs) of between -0,0003 and -0,00003 were used for risk-seeking decision makers. RAC of between 0,00003 and 0,0003 were used for risk-averse decision makers.

An enterprise budget for irrigation maize was constructed. Irrigation systems with application capacities of 135 $m^3/h$ and 200 $m^3/h$ were used to irrigate two soil types. The one was a Hutton/Deverton soil with a plant extractable soil water (PESW) of 138 mm. The other was an Avalon/Bergville soil with a PESW of 77 mm.

Two load management scenarios were constructed. The first scenario assumed that irrigation farmers could apply irrigation water 24 hours every day of the week. The second scenario assumed that irrigation farmers were limited to 12 hours pumping per day.

The GSD program of Cochran and Raskin was used to calculate the amount of incentive required by each type of decision maker under all the anticipated management and production conditions.

The results indicated that the introduction of pumping restrictions reduced net returns by between R11/ha and R136/ha. The size of the reduction in net returns was influenced by the application capacity of the irrigation system and the soil's PESW.

Irrigation farmers must adjust their irrigation-scheduling strategies to minimize the impact of pumping restrictions. Generally, irrigation water is applied sooner (higher depletion levels) if pumping restrictions are introduced or the soil's PESW is lowered.

Pumping restrictions affected both the expected maize yield and the amount of irrigation water applied. As expected, maize yields on average decline when pumping restrictions were introduced. However, in contrast to the decline in the average maize yields, the average amount of irrigation water applied, increased when pumping time was restricted. The reason was that irrigation was triggered at higher soil-water levels when pumping was restricted.

The amount of discount in the cost of electricity that should be offered by ESKOM to keep expected net returns from falling when load management is imposed, varied between R6/ha and R282/ha. The amount of discount required increased with risk aversion. In addition, the required subsidies were significantly reduced when the application capacity of the irrigation system increased or the PESW of the soil increased.

It is clear that the economic profitability, and therefore also the adoption of the proposed Ruraflex load management program, will be affected by the financial incentive offered (reduction in the cost of electricity), the risk preference of the irrigation farmer, the application capacity of the irrigation system and the soil's PESW and the efficiency with which irrigation farmers can adjust their irrigation-scheduling strategies to the load management program.

The importance of proper irrigation scheduling will increase under load management conditions. The failure to adjust the soil-water depletion levels will increase yield losses in the drier weather years. An over-adjustment in the soil-water depletion levels will result in more irrigation water being applied.

The findings of this research were that load management programs could potentially increase the economic efficiency of irrigation farming. Some irrigation farmers, however, would be better off by not participating in load management programs, because of low application capacities of irrigation systems, poor quality soils, high risk aversion and/or the inability to adjust irrigation management to load management programs.

## CONCLUSIONS AND RECOMMENDATIONS

Better information has the ability to limit the adverse effects of droughts (water availability) and soil quality. However, better information has diminishing returns and relatively low levels of information have the ability to account for a relatively large percentage of the benefits from perfect information.

Although special attention needs to be given to information systems in agriculture, it is questionable whether highly specialized and sophisticated irrigation-information systems are the answer to the inefficiency with which irrigation water is used. Research and extension in the field of irrigation information should rather focus on means to improve the way in which information is conveyed and used by irrigation farmers. Special attention needs to be paid to the adjustment of information systems to suit the specific farm operation and farm manager.

Irrigation farmers would be willing to pay for better irrigation information, especially if the availability of irrigation water is limited and the soil quality is poor. However, it is not necessary to acquire the highest level of irrigation information. It is more important to make sure that the information is applied and used correctly. It is potentially easier to suffer big income losses due to the incorrect use of the available information than it is to use less sophisticated information. However, the chance of using information incorrectly increases as the level of sophistication of the information decreases.

It is clear that financial incentives must be offered to the irrigation farmers not to make them worse off when load management strategies are introduced. Irrigation farmers therefore must ensure that the per hectare savings in the cost of electricity due to the use of cheaper electricity are at least equal to the amount of subsidy required not to make them worse off by restricting pumping hours. It is clear that the economic profitability, and therefore also the adoption of the proposed Ruraflex load management program, will be affected by the financial incentive offered (reduction in the cost of electricity), the risk preference of the irrigation farmer, the application capacity of the irrigation system and the soil's PESW and the efficiency with which irrigation farmers can adjust their irrigation-scheduling strategies to the load management program.

## IMPLICATIONS FOR FURTHER RESEARCH

The focus of this research was to use the *ex ante* approach to value irrigation information on an annual basis. Consequently, the possibility of learning over time was ignored. An extension of this work would be to value irrigation information on a real-time, multi-year basis. The wealth-risk preferences elicited in Chapter 3 can be used to value irrigation information in such a setting.

Representative farms have many applications in the evaluation of different management strategies. The procedure used in the formulation of the representative farms can be applied in other areas.

The SIMCOM model's search procedure can be adjusted to search in a sequential control fashion, optimizing in a time span following the period when the decision is to be made. Everything that has happened up to the time the decision is made, is taken as fixed and everything in the future as the best guess or based on historical events that represent the same period of the growing season. It would be very interesting to compare the value of information determined using the sequential control approach to the results obtained in this research.

More research attention needs to be given to the decision-making process of farmers. For example, do decision makers use their information optimally? What are the management needs of the decision maker to successfully implement and operate a better-irrigation-information strategy? Evaluating information thus can also contribute to understanding why irrigation farmers often do not use socially desirable and economically productive management practices.

The value of information obtained by using the simulation and optimization approach could be verified by using, for example, the contingent valuation method. The farmers in the Winterton area might be asked questions (by playing a bidding game) in an attempt to determine their willingness to pay for better irrigation information.

The value of information for other representative farms in the Winterton area and elsewhere should be determined. The sensitivity of the value to changes in enterprise selection, farm size and other important economic variables should be determined.

An extension of this research would be to determine to what extent the frequency and amount of rainfall affect the value of information. The relatively high rainfall in the research area resulted in errors made by using less sophisticated irrigation frequently being corrected when rain refilled the soil profile. A preliminary hypothesis would be that the value of irrigation information would increase as the frequency and amount of rainfall decrease.

The reason for the differences between annual income and wealth-risk preferences should be investigated further.

The SIMCOM model can be applied to various decision-making problems on irrigation farms. For example, the SIMCOM model can be used to evaluate the effect of different pumping restrictions and electricity-management strategies on the economic profitability of irrigation farming. It can also be used to determine the optimum planting dates, plant populations and other management practices.

The availability of experimental data proved to be the most limiting factor affecting the validation of crop models. Another important limiting factor was the genetic coefficients used in crop-growth models.

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# APPENDIX A

# VALIDATION DATA AND RESULTS

Table A1 Experimental data obtained for maize, wheat and soybeans under different production and management conditions in South Africa, 1993

| EXPERI-MENT | PLANTING DATE | CULTI-VAR | PLANT POPULATION (PLANT/m²) | ROW SPACING (m) | IRRI-GATION (mm/ha) | PRODUCTION COST (R/ha) |
|---|---|---|---|---|---|---|
| POTCHEFSTROOM (MAIZE) | | | | | | |
| 1. | 07-09-90 | PNR473/AND | 2,0 | 1,0 | 563 | 493 |
| 2. | 14-09-90 | A1894W/AND | 2,0 | 1,0 | 563 | 493 |
| 3. | 24-09-90 | PNR6363 | 2,0 | 1,0 | 563 | 493 |
| 4. | 28-09-90 | | 2,0 | 1,0 | 563 | 493 |
| 5. | 05-10-90 | | 2,0 | 1,0 | 563 | 493 |
| 6. | 12-10-90 | | 2,0 | 1,0 | 563 | 493 |
| 7. | 19-10-90 | | 2,0 | 1,0 | 563 | 493 |
| 8. | 26-10-90 | | 2,0 | 1,0 | 563 | 493 |
| 9. | 02-11-90 | | 2,0 | 1,0 | 563 | 493 |
| 10. | 09-11-90 | | 2,0 | 1,0 | 563 | 493 |
| 11. | 16-11-90 | | 2,0 | 1,0 | 563 | 493 |
| 12. | 23-11-90 | | 2,0 | 1,0 | 563 | 493 |
| 13. | 29-11-90 | | 2,0 | 1,0 | 563 | 493 |
| 14. | 07-12-90 | | 2,0 | 1,0 | 563 | 493 |
| 15. | 14-12-90 | | 2,0 | 1,0 | 563 | 493 |
| 16. | 21-12-90 | | 2,0 | 1,0 | 563 | 493 |
| 17. | 28-12-90 | | 2,0 | 1,0 | 563 | 493 |
| 18. | 04-01-91 | | 2,0 | 1,0 | 563 | 493 |
| 19. | 11-01-91 | | 2,0 | 1,0 | 563 | 493 |
| 20. | 18-01-91 | | 2,0 | 1,0 | 563 | 493 |
| 21. | 25-01-91 | | 2,0 | 1,0 | 563 | 493 |
| OTTOSDAL (MAIZE) | | | | | | |
| 1. | 18-12-90 | PNR473 | 1,5 | 0,8 | 0 | 493 |
| 2. | 18-12-90 | PNR473 | 1,8 | 1,0 | 0 | 493 |
| 3. | 18-12-90 | PNR473 | 1,5 | 1,5 | 0 | 493 |
| 4. | 18-12-90 | PNR473 | 1,2 | 2,0 | 0 | 493 |
| 5. | 18-12-90 | PNR473 | 1,3 | 2,5 | 0 | 493 |
| 6. | 18-12-90 | PNR473 | 1,1 | 3,0 | 0 | 493 |
| ROOIPOORT (MAIZE) | | | | | | |
| 1. | 23-11-88 | PNR473 | 2,5 | 1,4 | 0 | 493 |
| PK LE ROUX (MAIZE) | | | | | | |
| 1. | 09-12-90 | PNR496 | 4,4 | 0,75 | 578 | 1 158 |
| 2. | 25-11-90 | SNK2232 | 4,4 | 0,75 | 955 | 1 158 |
| 3. | 24-09-90 | PNR6528 | 4,4 | 0,75 | 903 | 1 158 |
| 4. | 30-09-90 | PNR6528 | 4,4 | 0,75 | 636 | 1 158 |
| 5. | 25-09-90 | PNR6528 | 4,4 | 0,75 | 1015 | 1 158 |

Table A1 (*continued*)

| EXPERI-MENT | PLANTING DATE | CULTI-VAR | PLANT POPULATION (PLANT/m²) | ROW SPACING (m) | IRRI-GATION (mm/ha) | PRODUCTION COST (R/ha) |
|---|---|---|---|---|---|---|
| **GLEN (MAIZE)** | | | | | | |
| 1. | 03-01-90 | PNR473 | 2,0 | 1,0 | 0 | 206 |
| 2. | | | 1,3 | 1,5 | 0 | 206 |
| 3. | | | 1,0 | 2,0 | 0 | 206 |
| **GLEN (MAIZE)** | | | | | | |
| 1. | 20-12-89 | PNR6528 | 2,0 | 1,0 | 0 | 206 |
| 2. | | | 1,3 | 1,5 | 0 | 206 |
| 3. | | | 1,0 | 2,0 | 0 | 206 |
| **CEDARA (MAIZE)** | | | | | | |
| 1. | 23-10-90 | RS5206 | 4,3 | 0,75 | 0 | 1 264 |
| 2. | | PNR6463 | 4,3 | 0,75 | 0 | 1 264 |
| 3. | | PNR6363 | 4,1 | 0,75 | 0 | 1 264 |
| 1. | 13-11-90 | RS5206 | 4,4 | 0,75 | 0 | 1 264 |
| 2. | | PNR6463 | 4,5 | 0,75 | 0 | 1 264 |
| 3. | | PNR6363 | 4,4 | 0,75 | 0 | 1 264 |
| 1. | 03-12-90 | RS5200 | 4,4 | 0,75 | 0 | 1 264 |
| 2. | | PNR6463 | 4,4 | 0,75 | 0 | 1 264 |
| 3. | | PNR6363 | 4,5 | 0,75 | 0 | 1 264 |
| **GLEN (WHEAT)** | | | | | | |
| 1. | 18-05-89 | Scheepers | 22,2 | 0,45 | 0 | 332 |
| 2. | | Scheepers | 16,8 | 0,60 | 0 | 332 |
| 3. | | Scheepers | 13,3 | 0,75 | 0 | 332 |
| **PK LE ROUX (WHEAT)** | | | | | | |
| 1. | 04-07-86 | SST66 | 300,0 | 0,15 | 651 | 1 241 |
| 2. | 07-07-86 | SST66 | 288,0 | 0,15 | 534 | 1 241 |
| 3. | 18-06-86 | SST66 | 228,0 | 0,15 | 446 | 1 241 |
| 4. | 19-06-86 | SST66 | 228,0 | 0,15 | 515 | 1 241 |
| 5. | 10-07-86 | SST66 | 228,0 | 0,15 | 439 | 1 241 |
| 6. | 16-07-86 | SST66 | 228,0 | 0,15 | 629 | 1 241 |
| 7. | 04-07-86 | SST66 | 228,0 | 0,15 | 555 | 1 241 |
| **ROODEPLAAT (WHEAT)** | | | | | | |
| 1. | 21-06-89 | SST66 | 222,0 | 0,25 | 50 | 1 801 |
| 2. | | SST66 | 222,0 | 0,25 | 145 | 1 801 |
| 3. | | SST66 | 222,0 | 0,25 | 281 | 1 801 |
| 4. | | SST66 | 222,0 | 0,25 | 354 | 1 801 |
| 5. | | SST66 | 222,0 | 0,25 | 450 | 1 801 |
| 6. | | SST66 | 222,0 | 0,25 | 513 | 1 801 |

Table A1 *(continued)*

| EXPERI-MENT | PLANTING DATE | CULTI-VAR | PLANT POPULATION ($PLANT/m^2$) | ROW SPACING (m) | IRRI-GATION (mm/ha) | PRODUCTION COST (R/ha) |
|---|---|---|---|---|---|---|
| **PRESTON PARK (WHEAT)** | | | | | | |
| 1. | 13-05-82 | Palmiet | 184,0 | 0,17 | 0 | 626 |
| 2. | 13-06-82 | Palmiet | 184,0 | 0,17 | 0 | 626 |
| 3. | 19-05-83 | Palmiet | 264,0 | 0,17 | 0 | 626 |
| 4. | 18-06-84 | Palmiet | 264,0 | 0,17 | 0 | 626 |
| 5. | 18-07-84 | Palmiet | 264,0 | 0,17 | 0 | 626 |
| 6. | 20-05-85 | Palmiet | 264,0 | 0,17 | 0 | 626 |
| 7. | 04-07-85 | Palmiet | 264,0 | 0,17 | 0 | 626 |
| 8. | 08-06-86 | Palmiet | 290,0 | 0,17 | 0 | 626 |
| 9. | 21-06-87 | Palmiet | 240,0 | 0,17 | 0 | 626 |
| 10. | 31-05-88 | Palmiet | 240,0 | 0,17 | 0 | 626 |
| 11. | 14-06-89 | Palmiet | 240,0 | 0,17 | 0 | 626 |
| 12. | 14-05-90 | Palmiet | 240,0 | 0,17 | 0 | 626 |
| 13. | 10-06-90 | Palmiet | 240,0 | 0,17 | 0 | 626 |
| **CEDARA (SOYBEAN)** | | | | | | |
| 1. | 01-12-81 | Forrest | 18,5 | 0,75 | 0 | 733 |
| 2. | 24-11-82 | Forrest | 25,8 | 0,75 | 0 | 733 |
| 3. | 05-12-83 | Forrest | 14,2 | 0,75 | 0 | 733 |
| 4. | 22-11-84 | Forrest | 19,7 | 0,75 | 0 | 733 |
| 5. | 28-11-85 | Forrest | Hail | - | - | - |
| 6. | 25-11-88 | Forrest | 24,8 | 0,75 | 0 | 733 |
| 7. | 21-11-89 | Forrest | 30,7 | 0,75 | 0 | 733 |
| 8. | 29-10-90 | Forrest | 20,7 | 0,75 | 0 | 733 |
| **BETHLEHEM (SOYBEAN)** | | | | | | |
| 1. | 17-10-80 | BRA66 | 16,0 | 0,75 | 0 | 663 |
| 2. | 06-11-80 | BRA66 | 16,0 | 0,75 | 0 | 663 |
| 3. | 26-11-80 | BRA66 | 16,0 | 0,75 | 0 | 663 |
| 4. | 16-12-80 | BRA66 | 16,0 | 0,75 | 0 | 663 |
| **POTCHEFSTROOM (SOYBEAN)** | | | | | | |
| 1. | 19-11-81 | Forrest | 41,8 | 0,90 | 0 | 579 |
| 2. | 17-11-82 | Forrest | 37,6 | 0,75 | 0 | 579 |
| 3. | 01-12-83 | Forrest | 19,5 | 0,75 | 0 | 579 |
| 4. | 23-11-84 | Forrest | 26,8 | 0,75 | 0 | 579 |
| 5. | 21-11-85 | Forrest | Hail | - | - | - |
| 6. | 17-11-86 | Forrest | 21,1 | 0,60 | 0 | 579 |
| 7. | 19-11-87 | Forrest | 21,0 | 0,75 | 0 | 579 |
| 8. | 13-11-88 | Forrest | 31,6 | 0,75 | 0 | 579 |
| 9. | 21-11-89 | Forrest | 24,8 | 0,75 | 0 | 579 |
| 10. | 13-11-90 | Forrest | 23,9 | 0,75 | 0 | 579 |

Table A2 The actual and simulated yields, changes in soil-water levels and the calculated net returns (NR) for each of the maize, wheat and soybean treatments, 1993

| | YIELD (kg/ha) | | | CHANGE IN SOIL-WATER (mm/ha) | | | NR (R/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| NR. | ACTUAL | PUTU | IBSNAT | ACTUAL | PUTU | IBSNAT | ACTUAL | PUTU | IBSNAT |
| POTCHEFSTROOM (MAIZE - PNR473) | | | | | | | | | |
| 1. | 5 147 | 6 500 | 4 289 | 0 | 0 | 0 | 770 | 1 235 | 475 |
| 2. | 5 166 | 7 000 | 4 770 | 0 | 0 | 0 | 777 | 1 407 | 640 |
| 3. | 5 700 | 6 100 | 6 492 | 0 | 0 | 0 | 960 | 1 098 | 1 233 |
| 4. | 5 378 | 6 400 | 4 955 | 0 | 0 | 0 | 849 | 1 201 | 704 |
| 5. | 7 171 | 6 200 | 7 052 | 0 | 0 | 0 | 1 466 | 1 132 | 1 425 |
| 6. | 6 682 | 5 800 | 7 052 | 0 | 0 | 0 | 1 298 | 995 | 1 425 |
| 7. | 9 701 | 4 200 | 7 287 | 0 | 0 | 0 | 2 336 | 444 | 1 506 |
| 8. | 6 839 | 3 100 | 7 135 | 0 | 0 | 0 | 1 352 | 66 | 1 454 |
| 9. | 5 259 | 3 200 | 5 792 | 0 | 0 | 0 | 809 | 100 | 992 |
| 10. | 7 280 | 5 000 | 6 991 | 0 | 0 | 0 | 1 504 | 719 | 1 404 |
| 11. | 6 723 | 7 300 | 5 505 | 0 | 0 | 0 | 1 312 | 1 510 | 893 |
| 12. | 7 158 | 6 500 | 6 759 | 0 | 0 | 0 | 1 462 | 1 235 | 1 324 |
| 13. | 6 147 | 5 600 | 6 654 | 0 | 0 | 0 | 1 114 | 926 | 1 288 |
| 14. | 4 553 | 3 500 | 5 440 | 0 | 0 | 0 | 566 | 204 | 871 |
| 15. | 2 208 | 1 900 | 4 549 | 0 | 0 | 0 | -241 | -347 | 564 |
| 16. | 2 593 | 1 900 | 3 058 | 0 | 0 | 0 | -108 | -347 | 52 |
| 17. | 1 576 | 3 500 | 984 | 0 | 0 | 0 | -458 | 204 | -662 |
| 18. | 1 967 | 2 700 | 374 | 0 | 0 | 0 | -324 | -72 | -872 |
| 19. | 1 030 | 100 | 0 | 0 | 0 | 0 | -646 | -966 | -1 000 |
| 20. | 1 068 | 0 | 0 | 0 | 0 | 0 | -633 | -1 000 | -1 000 |
| 21. | 115 | 0 | 0 | 0 | 0 | 0 | -961 | -1 000 | -1 000 |
| POTCHEFSTROOM (MAIZE - A 1894 W) | | | | | | | | | |
| 1. | 7 076 | 6 500 | 6 641 | 0 | 0 | 0 | 1 433 | 1 235 | 1 284 |
| 2. | 5 293 | 7 000 | 6 766 | 0 | 0 | 0 | 820 | 1 407 | 1 327 |
| 3. | 7 144 | 6 100 | 7 072 | 0 | 0 | 0 | 1 457 | 1 098 | 1 432 |
| 4. | 6 683 | 6 400 | 7 171 | 0 | 0 | 0 | 1 298 | 1 201 | 1 466 |
| 5. | 6 460 | 6 200 | 7 467 | 0 | 0 | 0 | 1 222 | 1 132 | 1 568 |
| 6. | 7 077 | 5 800 | 7 577 | 0 | 0 | 0 | 1 434 | 995 | 1 606 |
| 7. | 6 708 | 4 200 | 7 543 | 0 | 0 | 0 | 1 307 | 444 | 1 594 |
| 8. | 4 364 | 3 100 | 7 434 | 0 | 0 | 0 | 501 | 66 | 1 557 |
| 9. | 6 050 | 3 200 | 7 732 | 0 | 0 | 0 | 1 081 | 100 | 1 659 |
| 10. | 6 216 | 5 000 | 7 796 | 0 | 0 | 0 | 1 138 | 719 | 1 681 |
| 11. | 6 757 | 7 300 | 7 479 | 0 | 0 | 0 | 1 324 | 1 510 | 1 572 |
| 12. | 6 921 | 6 500 | 7 164 | 0 | 0 | 0 | 1 380 | 1 235 | 1 464 |
| 13. | 6 628 | 5 600 | 5 834 | 0 | 0 | 0 | 1 279 | 926 | 1 006 |
| 14. | 6 132 | 3 500 | 4 501 | 0 | 0 | 0 | 1 109 | 204 | 548 |
| 15. | 3 953 | 1 900 | 4 093 | 0 | 0 | 0 | 359 | -347 | 407 |
| 16. | 2 626 | 1 900 | 2 533 | 0 | 0 | 0 | -97 | -347 | -129 |
| 17. | 1 872 | 3 500 | 1 340 | 0 | 0 | 0 | -356 | 204 | -539 |
| 18. | 2 733 | 2 700 | 433 | 0 | 0 | 0 | -60 | -72 | -851 |
| 19. | 2 139 | 100 | 0 | 0 | 0 | 0 | -265 | -966 | -1 000 |
| 20. | 1 199 | 0 | 0 | 0 | 0 | 0 | -588 | -1 000 | -1 000 |
| 21. | 326 | 0 | 0 | 0 | 0 | 0 | -888 | -1 000 | -1 000 |

Table A2 *(continued)*

| NR. | YIELD (kg/ha) ACTUAL | PUTU | IBSNAT | CHANGE IN SOIL-WATER (mm/ha) ACTUAL | PUTU | IBSNAT | NR (R/ha) ACTUAL | PUTU | IBSNAT |
|---|---|---|---|---|---|---|---|---|---|
| POTCHEFSTROOM (MAIZE - PNR6363) | | | | | | | | | |
| 1. | 5 436 | 6 500 | 5 940 | 0 | 0 | 0 | 869 | 1 235 | 1 043 |
| 2. | 5 989 | 7 000 | 5 713 | 0 | 0 | 0 | 1 060 | 1 407 | 965 |
| 3. | 5 389 | 6 100 | 6 007 | 0 | 0 | 0 | 853 | 1 098 | 1 066 |
| 4. | 6 349 | 6 400 | 6 234 | 0 | 0 | 0 | 1 183 | 1 201 | 1 144 |
| 5. | 6 717 | 6 200 | 6 382 | 0 | 0 | 0 | 1 310 | 1 132 | 1 195 |
| 6. | 3 248 | 5 800 | 6 382 | 0 | 0 | 0 | 117 | 995 | 1 195 |
| 7. | 6 909 | 4 200 | 6 743 | 0 | 0 | 0 | 1 376 | 444 | 1 319 |
| 8. | 5 213 | 3 100 | 6 601 | 0 | 0 | 0 | 793 | 66 | 1 270 |
| 9. | 4 941 | 3 200 | 6 557 | 0 | 0 | 0 | 699 | 100 | 1 255 |
| 10. | 6 488 | 5 000 | 6 668 | 0 | 0 | 0 | 1 231 | 719 | 1 293 |
| 11. | 4 833 | 7 300 | 5 845 | 0 | 0 | 0 | 662 | 1 510 | 1 010 |
| 12. | 6 526 | 6 500 | 7 114 | 0 | 0 | 0 | 1 244 | 1 235 | 1 447 |
| 13. | 5 732 | 5 600 | 6 063 | 0 | 0 | 0 | 971 | 926 | 1 085 |
| 14. | 4 980 | 3 500 | 4 967 | 0 | 0 | 0 | 713 | 204 | 708 |
| 15. | 4 783 | 1 900 | 4 254 | 0 | 0 | 0 | 645 | -347 | 463 |
| 16. | 3 885 | 1 900 | 2 633 | 0 | 0 | 0 | 336 | -347 | -95 |
| 17. | 2 076 | 3 500 | 1 702 | 0 | 0 | 0 | -286 | 204 | -415 |
| 18. | 2 703 | 2 700 | 450 | 0 | 0 | 0 | -71 | -72 | -845 |
| 19. | 1 862 | 100 | 0 | 0 | 0 | 0 | -360 | -966 | -1 000 |
| 20. | 1 633 | 0 | 0 | 0 | 0 | 0 | -439 | -1 000 | -1 000 |
| 21. | 666 | 0 | 0 | 0 | 0 | 0 | -771 | -1 000 | -1 000 |
| OTTOSDAL (MAIZE - PNR473) | | | | | | | | | |
| 1. | 6 246 | 2 400 | 5 892 | 0 | 0 | 0 | 1 625 | 302 | 1 504 |
| 2. | 5 866 | 2 400 | 6 811 | 0 | 0 | 0 | 1 488 | 296 | 1 813 |
| 3. | 4 399 | 2 400 | 5 795 | 0 | 0 | 0 | 991 | 303 | 1 471 |
| 4. | 4 159 | 2 400 | 5 208 | 0 | 0 | 0 | 912 | 307 | 1 273 |
| 5. | 3 291 | 2 400 | 5 227 | 0 | 0 | 0 | 614 | 307 | 1 280 |
| 6. | 2 812 | 2 400 | 4 922 | 0 | 0 | 0 | 451 | 309 | 1 177 |
| ROOIPOORT (MAIZE - PNR473) | | | | | | | | | |
| 1. | 6 400 | 7 500 | 6 871 | 0 | 0 | 0 | 1 658 | 2 037 | 1 820 |
| PK LE ROUX (MAIZE - PNR496; SNK2232; PNR6528) | | | | | | | | | |
| 1. | 9 058 | 3 400 | 8 164 | -48 | 11 | -61 | 1 430 | -565 | 1 133 |
| 2. | 9 655 | 7 800 | 7 861 | 155 | 122 | 187 | 1 154 | 543 | 510 |
| 3. | 13 509 | 5 100 | 9 124 | -86 | 8 | -75 | 2 722 | -248 | 1 205 |
| 4. | 11 326 | 4 100 | 8 016 | -121 | -126 | -188 | 2 222 | -259 | 1 139 |
| 5. | 15 437 | 8 300 | 9 428 | 53 | -2 | 95 | 3 177 | 768 | 1 075 |

Table A2 *(continued)*

| | YIELD (kg/ha) | | | CHANGE IN SOIL-WATER (mm/ha) | | | NR (R/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| NR. | ACTUAL | PUTU | IBSNAT | ACTUAL | PUTU | IBSNAT | ACTUAL | PUTU | IBSNAT |
| GLEN (MAIZE - PNR473; PNR6528) | | | | | | | | | |
| 1. | 3 840 | 4 500 | 3 179 | -94 | -120 | -136 | 1 152 | 1 401 | 960 |
| 2. | 3 581 | 4 500 | 2 114 | -103 | -99 | -109 | 1 084 | 1 397 | 584 |
| 3. | 2 566 | 4 500 | 1 589 | -57 | -136 | -83 | 703 | 1 434 | 389 |
| 1. | 4 990 | 6 800 | 3 405 | -60 | -61 | -119 | 1 520 | 2 143 | 1 023 |
| 2. | 2 753 | 6 800 | 2 265 | 2 | -72 | -124 | 712 | 2 165 | 649 |
| 3. | 2 145 | 6 800 | 1 703 | 48 | -68 | -116 | 471 | 2 169 | 456 |
| CEDARA (MAIZE - RS5206; PNR6463; PNR6363) | | | | | | | | | |
| 1. | 10 338 | 6 200 | 9 974 | 54 | -3 | 38 | 3 218 | 1 843 | 3 107 |
| 2. | 9 031 | 6 200 | 8 139 | 39 | -40 | 40 | 2 781 | 1 873 | 2 474 |
| 3. | 9 039 | 6 200 | 10 306 | 31 | 17 | 40 | 1 737 | 772 | 2 165 |
| 1. | 10 329 | 9 500 | 10 417 | 21 | -4 | 45 | 2 183 | 1 918 | 2 193 |
| 2. | 9 825 | 9 500 | 9 192 | 8 | -40 | 24 | 2 018 | 1 947 | 1 787 |
| 3. | 8 864 | 9 500 | 14 654 | 54 | -3 | 38 | 1 656 | 1 922 | 3 660 |
| 1. | 4 809 | 9 900 | 8 446 | -80 | -107 | -75 | 367 | 2 141 | 1 614 |
| 2. | 5 995 | 9 900 | 9 826 | -61 | -40 | -5 | 760 | 2 086 | 2 032 |
| 3. | 6 266 | 9 900 | 15 153 | -65 | -107 | -83 | 855 | 2 140 | 3 927 |
| GLEN (WHEAT - SCHEEPERS) | | | | | | | | | |
| 1. | 890 | 2 590 | 1 019 | -97 | -106 | -105 | 272 | 1 314 | 357 |
| 2. | 820 | 2 590 | 1 150 | -221 | -106 | -103 | 334 | 1 316 | 437 |
| 3. | 910 | 2 590 | 1 256 | -102 | -106 | -103 | 295 | 1 322 | 507 |
| PK LE ROUX (WHEAT - SST66) | | | | | | | | | |
| 1. | 7 350 | 5 810 | 5 310 | 6 | 27 | 11 | 2 440 | 1 484 | 1 193 |
| 2. | 5 300 | 5 040 | 5 113 | -23 | -57 | 33 | 1 323 | 1 192 | 1 162 |
| 3. | 5 750 | 5 110 | 5 340 | -54 | -20 | -47 | 1 745 | 1 327 | 1 490 |
| 4. | 5 200 | 5 530 | 5 506 | -39 | 16 | 9 | 1 291 | 1 446 | 1 437 |
| 5. | 6 450 | 4 760 | 4 322 | -41 | -113 | -43 | 2 117 | 1 147 | 823 |
| 6. | 5 690 | 6 440 | 5 615 | 25 | -83 | 30 | 1 446 | 1 993 | 1 397 |
| 7. | 6 160 | 6 510 | 5 254 | 13 | -61 | 52 | 1 849 | 2 123 | 1 265 |
| ROODEPLAAT (WHEAT - SST66) | | | | | | | | | |
| 1. | 2 056 | 2 870 | 1 063 | -128 | -162 | -153 | -670 | -146 | -1 253 |
| 2. | 3 636 | 3 920 | 2 357 | -120 | -148 | -147 | 207 | 403 | -549 |
| 3. | 4 804 | 5 180 | 4 855 | -115 | -132 | -114 | 801 | 1 044 | 831 |
| 4. | 5 838 | 5 810 | 5 106 | -74 | -124 | -75 | 1 336 | 1 361 | 891 |
| 5. | 7 013 | 6 650 | 5 106 | -44 | -99 | 10 | 1 947 | 1 772 | 741 |
| 6. | 7 089 | 7 000 | 5 106 | -21 | -71 | 67 | 1 922 | 1 909 | 641 |

Table A2 (*continued*)

| | YIELD (kg/ha) | | | CHANGE IN SOIL-WATER (mm/ha) | | | NR (R/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| NR. | ACTUAL | PUTU | IBSNAT | ACTUAL | PUTU | IBSNAT | ACTUAL | PUTU | IBSNAT |
| PRESTON PARK (WHEAT - PALMIET) | | | | | | | | | |
| 1. | 1 700 | 4 060 | 1 512 | 0 | 0 | 0 | 256 | 1 693 | 142 |
| 2. | 1 400 | 3 640 | 1 348 | 0 | 0 | 0 | 73 | 1 437 | 42 |
| 3. | 4 500 | 5 040 | 1 691 | 0 | 0 | 0 | 1 894 | 2 223 | 184 |
| 4. | 1 000 | 2 450 | 215 | 0 | 0 | 0 | -237 | 646 | -715 |
| 5. | 300 | 1 890 | 1 890 | 0 | 0 | 0 | -663 | 305 | 305 |
| 6. | 600 | 840 | 234 | 0 | 0 | 0 | -480 | -334 | -703 |
| 7. | 300 | 2 450 | 187 | 0 | 0 | 0 | -663 | 646 | -732 |
| 8. | 2 500 | 3 010 | 1 005 | 0 | 0 | 0 | 655 | 966 | -255 |
| 9. | 1 300 | 2 940 | 1 240 | 0 | 0 | 0 | -34 | 964 | -71 |
| 10. | 1 900 | 3 360 | 224 | 0 | 0 | 0 | 331 | 1 220 | -689 |
| 11. | 2 000 | 3 570 | 972 | 0 | 0 | 0 | 392 | 1 348 | -234 |
| 12. | 2 900 | 4 060 | 1 555 | 0 | 0 | 0 | 940 | 1 646 | 121 |
| 13. | 3 300 | 4 270 | 1 892 | 0 | 0 | 0 | 1 184 | 1 774 | 326 |
| CEDARA (SOYBEAN - FORREST) | | | | | | | | | |
| 1. | 3 541 | 2 220 | 1 891 | 0 | 0 | 0 | 1 847 | 858 | 612 |
| 2. | 2 371 | 1 770 | 424 | 0 | 0 | 0 | 944 | 494 | -513 |
| 3. | 2 314 | 2 700 | 2 175 | 0 | 0 | 0 | 945 | 1 234 | 841 |
| 4. | 1 664 | 2 640 | 2 691 | 0 | 0 | 0 | 438 | 1 168 | 1 206 |
| 6. | 2 347 | 3 000 | 2 516 | 0 | 0 | 0 | 930 | 1 418 | 1 056 |
| 7. | 2 689 | 2 460 | 2 290 | 0 | 0 | 0 | 1 163 | 992 | 865 |
| 8. | 3 353 | 2 460 | 2 848 | 0 | 0 | 0 | 1 698 | 1 030 | 1 320 |
| BETHLEHEM (SOYBEAN - BRAGG) | | | | | | | | | |
| 1. | 2 022 | 1 950 | 1 983 | 0 | 0 | 0 | 790 | 736 | 761 |
| 2. | 2 002 | 2 130 | 2 302 | 0 | 0 | 0 | 775 | 871 | 1 000 |
| 3. | 1 894 | 2 430 | 2 040 | 0 | 0 | 0 | 694 | 1 096 | 804 |
| 4. | 1 129 | 2 610 | 1 298 | 0 | 0 | 0 | 122 | 1 230 | 249 |
| POTHCHEFSTROOM (SOYBEAN - FORREST) | | | | | | | | | |
| 1. | 3 036 | 1 290 | 208 | 0 | 0 | 0 | 1 536 | 230 | -580 |
| 2. | 846 | 1 140 | 167 | 0 | 0 | 0 | -87 | 133 | -595 |
| 3. | 2 490 | 840 | 136 | 0 | 0 | 0 | 1 211 | -24 | -550 |
| 4. | 3 243 | 1 440 | 601 | 0 | 0 | 0 | 1 747 | 398 | -230 |
| 6. | 1 784 | 1 920 | 805 | 0 | 0 | 0 | 677 | 778 | -56 |
| 7. | 2 438 | 1 800 | 905 | 0 | 0 | 0 | 1 166 | 689 | 19 |
| 8. | 2 658 | 2 220 | 1 292 | 0 | 0 | 0 | 1 291 | 964 | 269 |
| 9. | 1 555 | 1 710 | 522 | 0 | 0 | 0 | 492 | 607 | -281 |
| 10. | 1 981 | 1 560 | 675 | 0 | 0 | 0 | 814 | 499 | -164 |

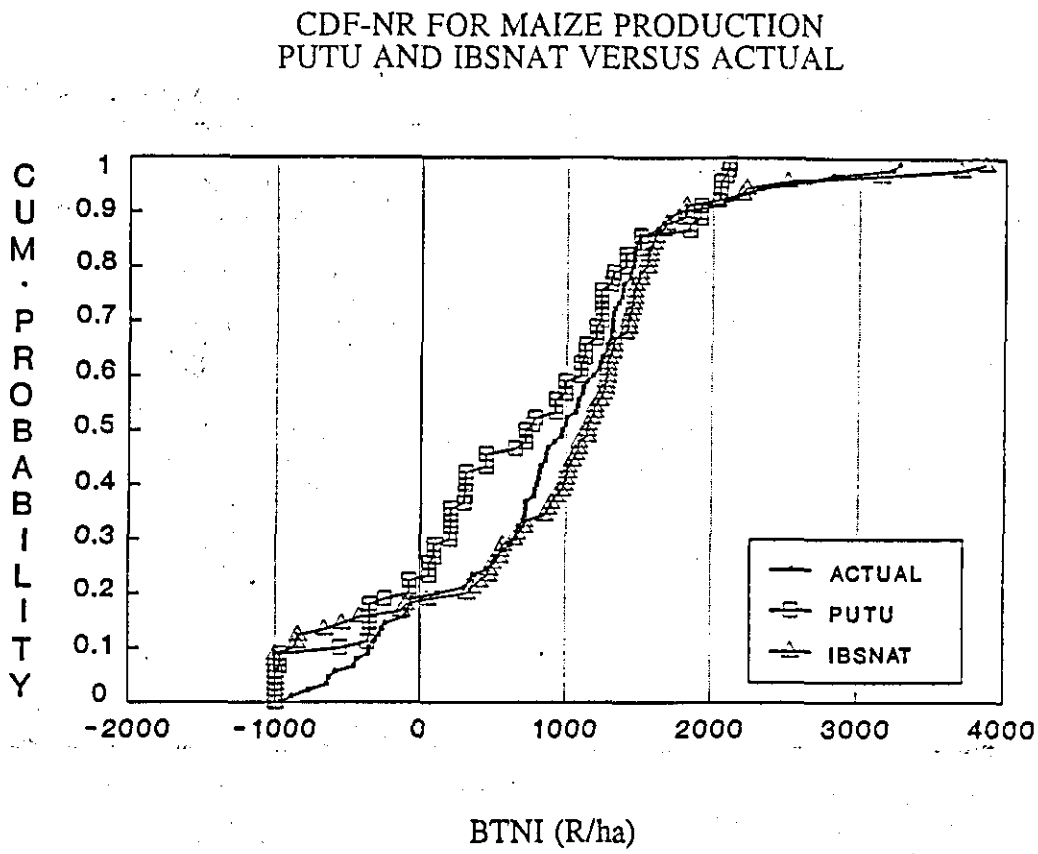


Figure A1 A comparison of the actual cumulative distribution function of net returns (CDF-NR) for maize with CDF-NR simulation by the PUTU irrigation and IBSNAT crop-growth simulation models

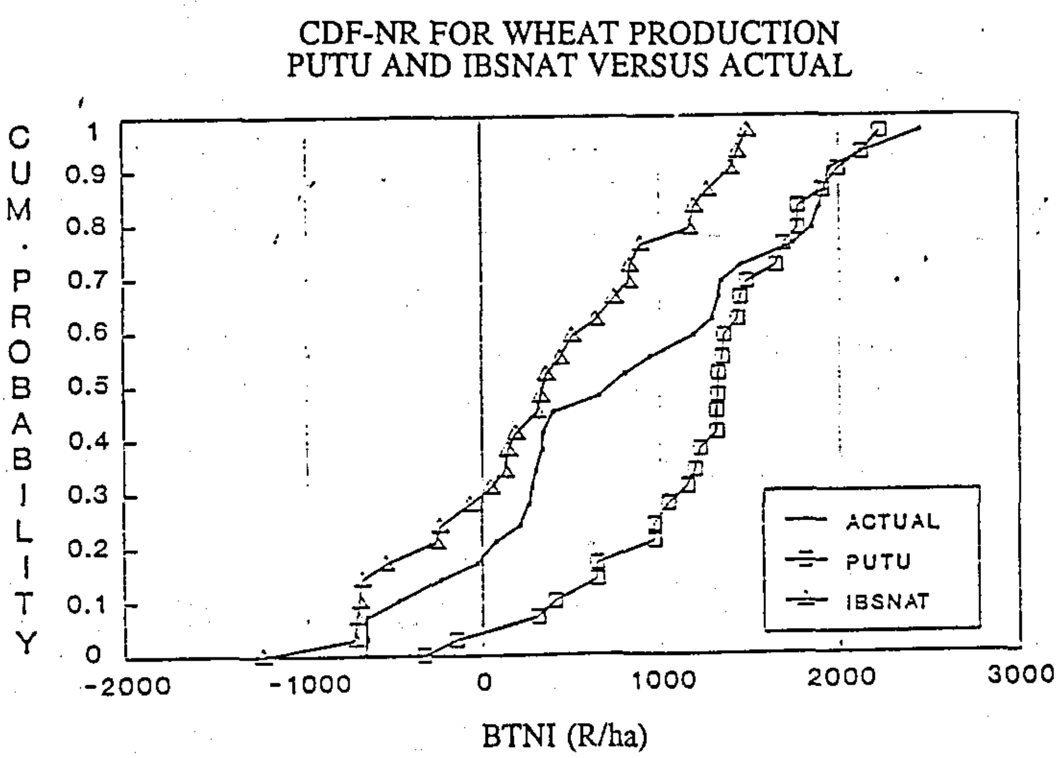


Figure A2 A comparison of the actual cumulative distribution function of net returns (CDF-NR) for wheat with CDF-NR simulation by the PUTU irrigation and IBSNAT crop-growth simulation models

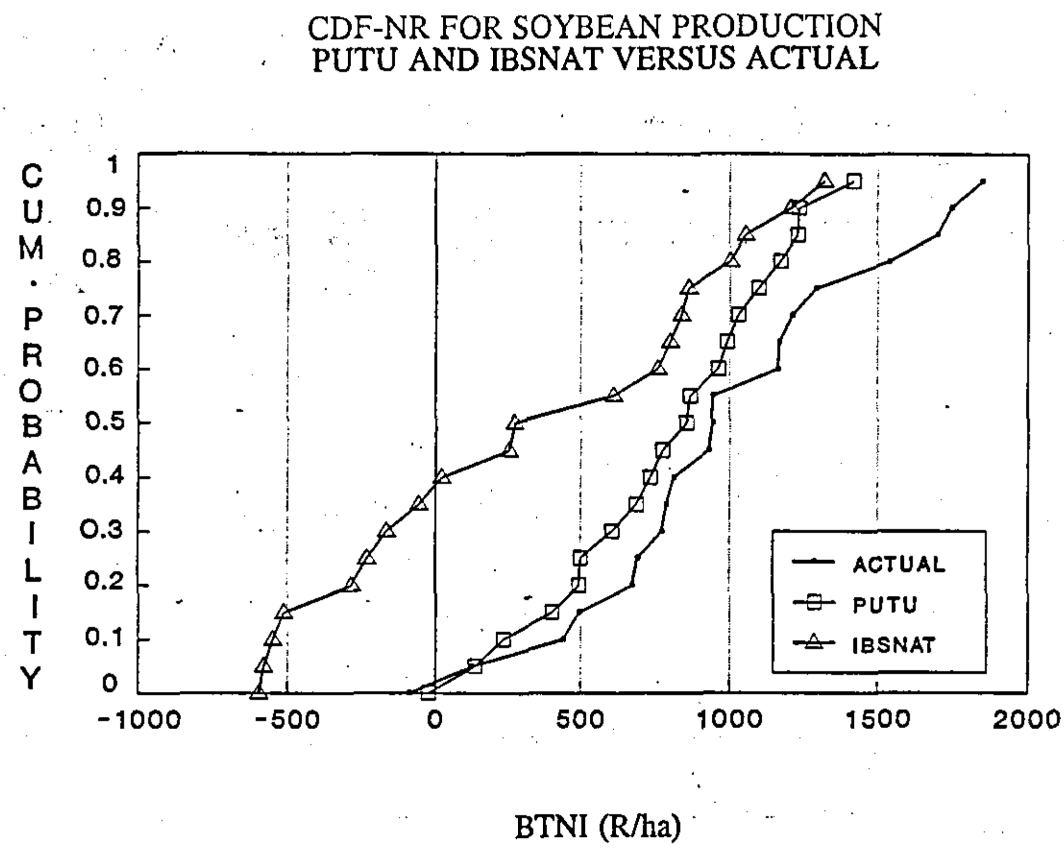


Figure A3 A comparison of the actual cumulative distribution function of net returns (CDF-NR) for soybeans with CDF-NR simulation by the PUTU irrigation and IBSNAT crop-growth simulation models

# APPENDIX B

## A REPRESENTATIVE IRRIGATION FARM IN THE WINTERTON AREA

### INTRODUCTION

Fixed and variable resources, activities and expenses for a representative irrigation farm in the Winterton area are presented here. First the procedure used in the construction of the representative farm is described. In the second section a description is given of the fixed resources. Variable resources, such as machinery and irrigation equipment are described in the third section. The fourth section deals with the identification of key economic variables. Annual overhead expenses are calculated in section five. Finally, a production system is identified and cash operating expenses are calculated.

The procedure for constructing a representative farm, Meiring (1989) was used to construct a representative irrigation farm in the Winterton area. First, a questionnaire was drawn up and administered to 53 irrigation farmers in the Winterton area. Relevant information about the farmer, farm business, fixed and variable resources, financial situation and production system was obtained. Distribution characteristics of the farmers' age, land use, irrigation systems and crops on irrigated farms in the Winterton area are presented in Table B1. The characteristics of the irrigated farms in the Winterton area are clearly very diverse. The standard deviations for all the measured variables are very large, especially in comparison with their averages. For example, the average farm size is 613 ha with a standard deviation of 1 048 ha. The number of hectares under irrigation varies between 10 and 320 ha, land used for dry-land crop production varies between 0 and 730 ha and land used for grazing varied between 0 and 1 500 ha. Rented land for irrigation, grazing and dry-land production is relatively small. Irrigation is used on about 47 % of the cultivated land. The predominant irrigation systems are centre pivots, which irrigate about 63 % of the land under irrigation. Drag line irrigation systems are very commonly used for the irrigation of pastures. Drag line systems irrigate about 26 % of the land under irrigation.

The data on irrigation, dry-land and grazing hectares were analyzed by using frequency distributions to identify the fixed resources for the representative farm. After selecting the irrigation, dry-land and grazing sizes, variable resources associated with these fixed resources were identified during group discussions. Participants in the group discussion were selected according to their farms' fixed-resource structures. Thirdly, the amount of equity present in farming operations in the Winterton area was analyzed by calculating a conservative market value debt-asset ratio from balance-sheet information obtained from the questionnaire and the local co-operative. Lastly, a representative production system was identified. Group discussions were again held to construct enterprise budgets for each of the enterprises in the selected production system.

## FIXED RESOURCES

An appropriate interval size for the total irrigation area was identified by changing the interval sizes and estimating the number of irrigation farms in each interval. After identifying an appropriate interval size it was determined that a relatively large percentage of the farmers could be placed in a total irrigation hectare interval ranging from 175 to 225 ha. The mid-point (200 ha) was taken as the number of hectares under irrigation on the representative farm. Land available for dry-land crop production and grazing was analyzed using the same metrology, but this time only the farms which irrigate between 175 and 225 ha were taken into account. Typically, farms in this category, also have limited land available for dry-land crop production and again relatively large grazing areas. The number of hectares available for dry-land crop production and grazing were taken to be 50 and 300 ha, respectively. No additional land was rented. Total farm size amounts to 550 ha.

About 85 % of the area under irrigation is irrigated by centre pivot irrigation systems. Predominantly cash crops are cultivated under these irrigation systems. Drag line irrigation systems are also fairly common in the research area. These systems are more commonly used for the production of pastures. Irrigation systems in the area have gross application capacities that vary between 4 and 8 mm/day and are pumping, on average, at a height of 35 metres.

Avalon and Hutton soils are predominantly used for cash crop production. A 1 050 mm deep Hutton/Deverton soil and a 800 mm deep Avalon/Bergville soil were identified by the Grain Crops Institute for Agricultural Research at Cedara as two fairly representative soil types. This was also confirmed by extension officers in the area. The plant available water capacity for the two soils was 77 mm (96 mm/m) and 138 mm (131 mm/m), respectively.

## VARIABLE RESOURCES

A questionnaire was drawn up and administered in a group discussion to determine the machinery and irrigation equipment requirements for the representative farm. The type, size, age, quantity, economic lifetime, market value and purchasing price for all the machinery equipment or items were obtained. Irrigation equipment selected for the 200 ha irrigated land was also identified. One hundred and seventy hectare is irrigated by centre pivots (50 ha, 60 ha, 60 ha), while the remaining 30 ha is irrigated by a drag line system. All the required machinery and irrigation equipment is listed in Table B2 in the Appendix.

The listed prices of the machinery were obtained from the Guide to Machinery Cost (Department of Agriculture, 1993). Quotations for the 50 ha, 60 ha and 30 ha drag line systems were obtained from AGRICO Machinery (PTY.) LTD., Estcourt. The centre pivot irrigation systems were designed to apply 6,5 mm of water per 24 hours (gross) at 35 metres of pressure. The drag line irrigation system was designed with a gross application capacity of 4 mm per 24 hours. Assuming an 80 % application efficiency, the centre pivot irrigation systems are capable of applying 5,2 hectare millimetres effectively every 24 hours. The 20 % water loss is due to evaporation, wind and non-uniform sprinkler coverage. The list price of these irrigation systems, broken down into pumps, motors, underground pipes, above-ground pipes, the sprinkler system and electrical cables, is also presented in Table B2.

## IMPORTANT ECONOMIC VARIABLES

The amount of equity in the farming operation has a heavy bearing on the net returns generated. Balance-sheet information was obtained from the questionnaire and the local branch of Natal Agricultural Co-operative. Based on these data, an average debt-asset ratio of about 25 % was identified. Land, machinery and irrigation equipment were valued at conservative market values. From the obtained financial data it was also established that liabilities consisted of 50 % long-term, 10 % medium-term and 40 % short-term debt.

## OVERHEAD COST

Next, the annual overhead cost for the representative farm was calculated. Overhead cost is categorized as depreciation, insurance, interest and other miscellaneous overhead expenses. The cost in each category is calculated and presented in four tables located in the Appendix. Table B2 deals with annual depreciation cost; Table B3 deals with annual insurance cost; Table B4 deals with annual interest cost; and Table B5 deals with the miscellaneous farm overhead expenses.

Depreciation cost on all the machinery and irrigation equipment is presented in Table B2. The lifetime, salvage percentage and list prices are also presented in Table B2. The depreciation cost was calculated by using the straight-line method. Total annual depreciation cost is R140 439 per year.

Table B3 lists the insured equipment or items, their market value, and the type of insurance used. Again all the information was obtained from the group discussions. This information was sent to SENTRABOER, that provided the insurance premium for each item. Total annual insurance cost amounts to R23 116. However, the cost of crop insurance is not included here, but in the crop enterprise budgets.

The long-, medium- and short-term liabilities, on which interests were paid, were obtained by first calculating the total asset value. Conservative market values, as used by the Co-operative, were used. These market values were verified by extension officers and other specialists in the area. The market value of land under centre pivot irrigation (excluding the irrigation system) is taken as R1 500 per hectare, R1 200 per hectare for land under other type of irrigation systems, R800 per hectare for land under dry-land crop production and R600 per hectare for grazing land. Irrigation systems were valued at R4 000 per hectare for centre pivot irrigation systems, while other types of irrigation systems were valued at R1 300 per hectare. Secondly, total liability was calculated by using the 40 % debt-asset ratio. Thirdly, the calculated total liability was categorized according to the obtained relationship between long-, medium- and short-term liabilities (50:10:40). Finally, the amount of long-, medium- and short-term interest paid annually by the farmer was calculated by using long-, medium- and short-term interest rates of 16, 21 and 18 %, respectively.

The short-, medium- and long-term assets of the representative farm are presented in Table B4. Total assets are valued at R1 988 100. Total liability on which interest is paid, is R795 240 (40 % of the assets). The annual long-, medium- and short-term interest paid is respectively R63 619, R16 700 and R57 257. The total interest paid annually is R137 576.

Miscellaneous overhead expenses for the representative farm are presented in Table B5. These include fixed water cost, at a flat rate of R180 per irrigated hectare; fixed electricity cost, as calculated by the IRRCOST computer program (Meiring, 1989); fixed labour cost and other overhead expenses such as telephones and licenses. Total miscellaneous overhead expenses was R100 173.

Annual total overhead cost for the representative 200 ha irrigation farm in the Winterton area is R401 304.

VARIABLE COST

*Variable cost consists of production cost (PC), irrigation variable cost (IC) and yield* variable cost (YC).

The variable cost of applying irrigation water was calculated by using the IRRCOST computer program (Meiring, 1989). The variable cost of applying one millimetre of water per hectare for the centre pivot irrigation systems is 64 cent per millimetre, while the variable cost for the drag line system is 73 cent per millimetre. IC is relatively low, because it consists mainly of variable electricity cost. The fixed electricity cost associated with each of the irrigation systems is listed in Table B5. The cost of water is excluded, because water cost does not vary per cubic metre, but is paid annually at a flat rate of R180 per ha. The amount of water applied by using a specific irrigation-scheduling strategy, will determine IC.

Yield variable cost consists of the cost of harvesting the crop and the cost for transportation. The representative farm has all the equipment to perform both these activities. The ownership cost of this equipment is included as overhead cost (Table B2). Total variable cost for operating the harvesters amounts to R54,78 per hour (Department of Agriculture, 1993). Harvesting cost, in rand per hectare, was calculated by multiplying R54,78 per hour by the appropriate harvesting speed (ha/hour). Harvesting speeds, at different yields, were used as given by the Guide to Machinery Cost (Department of Agriculture, 1993). The variable cost for operating all the hauling equipment (lorries and trailers) is 15,4 cent per ton per kilometre. In the group discussions it was established that 30 km should be used as the distance from the farm to the grain silo and back.

Although production practices in the area are very diverse, it was clear that irrigation farmers with fixed resources similar to those of the representative farm, have relatively large cash crop-production systems in conjunction with a relatively large beef-production system. After discussions with farmers and extension officers, it was decided that a beef-production system should be combined with the production of maize.

Enterprise budgets for dry-land maize, irrigated maize, a 100 cow-calf production unit, 100 head of cattle utilizing maize stubble and 60 head of cattle utilizing the kikuyu/ryegrass pastures, were drawn up by conducting separate group discussions with farmers. Both the 60 and 100 groups of cattle are bought annually for speculation purposes. The enterprise budgets for dry-land and irrigation maize are presented in Tables B6 and B7 respectively. The enterprise budgets for the 100 cow-calf production unit and the 60 speculation cattle on kikuyu/ryegrass pastures were incorporated into one budget (Table B8), because both enterprises use the kikuyu/ryegrass pastures. The enterprise budget for the 100 cattle on maize stubbles is presented in Table B9. Note that the gross incomes are not included with the enterprise budgets, because yields and product prices are stochastically varied. Production risk is incorporated by simulating dry-land and irrigation maize yields under different weather conditions. Stochastic maize and beef prices are used to incorporate price risk in the analyses. YC and IC are omitted from the enterprise budgets, because they are calculated separately. Two other cost items, which are not included in the enterprise budgets, are interest and fixed labour cost. Both these cost items are included as overhead costs. The remaining items in the enterprise budgets represent the production cost.

Maize is produced under centre pivots and on dry-land. Cultivation practices for dry-land maize and irrigation maize are fairly similar. After the cattle have been taken off the maize stubble (end of September), the fields are first disced and then ploughed or ripped. Once every five years lime is spread. Planting begins in mid-November and is preceded by seed-bed preparation. Weeds and grasses are controlled by applying weed and grass killers during a single spray operation at planting. Apart from the fertilizer, applied during planting, nitrogen is again applied towards the end of December. One hundred and twenty kilograms are applied per hectare in the case of dry-land maize, while 400 kg/ha is used for maize under irrigation. Weeds are controlled again, but this time using air spraying. During February and March four casual labourers are hired for weed control. These four labourers take about three weeks to clean 100 ha of maize. Eight additional casual labourers are hired during harvesting to help pick up the maize cobs. From Tables B6 and B7 respectively, it can be seen that the production cost (PC) for producing dry-land maize is estimated as R822 per hectare, and the PC for irrigation maize is estimated as R1 198 per hectare.

The enterprise budget for a 100 cow-calf unit beef herd is presented in Table B8. The beef herd use 120 ha of maize stubble during the winter months, 300 ha grazing during the summer months and the kikuyu/ryegrass pastures for three months while calving. Excess kikuyu/ryegrass produced during the months of November through March is used by 60 head of speculation cattle. Annually 81 cattle are rounded off in a feedingpen where they are fattened using a predominantly maize feed. It was established that 800 kg of maize is needed per head of cattle over the fattening period. An additional 100 head of speculation cattle are bought to use the remaining 100 ha of maize stubble. These cattle are purchased at the beginning of July and are sold in October. A separate enterprise budget, presented in Table B9, was drawn up for the 100 head of speculation cattle. Maize stubble, valued at R35 per hectare, was included as cost for the speculation cattle, but as additional income in the maize enterprise budgets.

Table B1 Distribution characteristics of farmers' age, land use, irrigation systems and crops on irrigated farms (n = 50) in the Winterton area, 1993

| VARIABLE | MINIMUM | MAXIMUM | AVERAGE | STANDARD DEVIATION | COEFFICIENT OF VARIATION | SKEWNESS |
|---|---|---|---|---|---|---|
| **FARMER/MANAGER** | | | | | | |
| Age (years) | 24 | 71 | 45 | 11 | 25 | 0,10 |
| Farming experience (years) | 2 | 42 | 20 | 11 | 54 | 0,24 |
| **LAND USE (hectare)** | | | | | | |
| Own irrigation | 0 | 320 | 98 | 85 | 89 | 0,88 |
| Rented irrigation | 0 | 80 | 6 | 13 | 336 | 4,34 |
| Total irrigation | 10 | 320 | 104 | 85 | 82 | 0,79 |
| Own grazing | 0 | 5 600 | 442 | 971 | 223 | 3,76 |
| Rented grazing | 0 | 1 500 | 104 | 266 | 275 | 3,54 |
| Total grazing | 0 | 5 600 | 546 | 1 069 | 196 | 3,20 |
| Own dry-land | 0 | 730 | 89 | 126 | 141 | 2,88 |
| Rented dry-land | 0 | 225 | 25 | 55 | 210 | 2,36 |
| Total dry-land | 0 | 730 | 114 | 133 | 116 | 2,22 |
| Total farm size | 0 | 6 160 | 629 | 1 048 | 166 | 3,56 |
| **IRRIGATION SYSTEMS (hectare)** | | | | | | |
| Centre pivot | 0 | 320 | 63 | 79 | 126 | 1,24 |
| Drag lines | 0 | 110 | 26 | 25 | 96 | 1,22 |
| Flood/surface | 0 | 22 | 1 | 4 | 453 | 4,88 |
| Side roll | 0 | 46 | 4 | 11 | 264 | 2,81 |
| Micro | 0 | 0 | 0 | 0 | 0 | 0 |
| Travelling gun | 0 | 45 | 4 | 11 | 256 | 2,51 |
| Other | 0 | 46 | 2 | 8 | 499 | 4,87 |
| **CROPS (hectare)** | | | | | | |
| Dry-land cash crops | 0 | 280 | 80 | 80 | 100 | 0,87 |
| Dry-land pastures | 0 | 200 | 10 | 37 | 408 | 4,04 |
| Irrigated cash crops | 0 | 480 | 92 | 117 | 127 | 1,31 |
| Irrigated pastures | 0 | 131 | 26 | 31 | 118 | 1,06 |

Table B2 List of the machinery equipment and depreciation cost for a representative 200 ha irrigation farm in the Winterton area, 1993

| MACHINERY EQUIPMENT | LIFETIME (YEARS) | SALVAGE (%) | LIST (1) PRICE | DEPRECIATION (PER UNIT) | TOTAL (R) |
|---|---|---|---|---|---|
| 1 tractor (52 kW) | 20 | 10 | 98 218 | 4 420 | 4 420 |
| 2 tractors (60 kW) | 20 | 10 | 110 450 | 4 970 | 9 941 |
| 2 tractors (103 kW) | 20 | 10 | 210 115 | 9 455 | 18 910 |
| 1 combined harvester (4 row) | 10 | 10 | 371 689 | 33 452 | 33 452 |
| 1 unload wagon (4 ton) | 20 | 10 | 13 576 | 611 | 611 |
| 2 trailers (8 ton) | 25 | 10 | 19 300 | 695 | 1 390 |
| 1 water car (1000 l) | 20 | 10 | 1 000 | 45 | 45 |
| 1 mouldboard plough (3 furrow) | 30 | 10 | 3 100 | 93 | 93 |
| 2 disc harrows (2,5 m) | 20 | 10 | 29 500 | 1 328 | 2 655 |
| 2 rippers (5 tine) | 20 | 10 | 9 300 | 419 | 837 |
| 1 chisel plough (9 tine) | 20 | 10 | 10 650 | 479 | 479 |
| 2 cultivators (4 row) | 10 | 10 | 6 341 | 571 | 1 141 |
| 1 conskild (3,8 m) | 20 | 10 | 26 650 | 1 199 | 1 199 |
| 1 stubble chopper | 20 | 10 | 13 225 | 595 | 595 |
| 1 land roller (2,3 m) | 30 | 10 | 2 456 | 74 | 74 |
| 1 spike-tooth harrow (4 m) | 20 | 10 | 476 | 21 | 21 |
| 1 rotary harrow (4 m) | 25 | 10 | 11 900 | 428 | 428 |
| 1 maize planter (4 row) | 20 | 10 | 31 658 | 1 425 | 1 425 |
| 1 wheat planter (4 m) | 20 | 10 | 25 009 | 1 125 | 1 125 |
| 1 fertilizer spreader (600 l) | 10 | 10 | 5 600 | 504 | 504 |
| 1 lime spreader (5 ton) | 20 | 10 | 26 000 | 1 170 | 1 170 |
| 1 boom sprayer (1 500 l) | 10 | 10 | 18 750 | 1 688 | 1 688 |
| 1 hammermill | 20 | 10 | 10 837 | 488 | 488 |
| 1 feed mixer | 20 | 10 | 16 267 | 732 | 732 |
| 1 disc mower (1,5 m) | 10 | 10 | 12 700 | 1 143 | 1 143 |
| 1 hay-rake (4 wheel) | 20 | 10 | 2 202 | 99 | 99 |
| 1 baler (1,2 m) | 10 | 10 | 50 038 | 4 503 | 4 503 |
| 1 fork-lifter | 30 | 10 | 500 | 15 | 15 |
| 1 forage harvester | 20 | 10 | 14 150 | 637 | 637 |
| 2 bakkies | 10 | 10 | 41 396 | 3 726 | 7 451 |
| 1 lorry (8 ton) | 20 | 10 | 230 500 | 10 373 | 10 373 |
| TWO 60 ha IRRIGATION SYSTEMS | | | | | |
| 2 pumps | 15 | 15 | 10 178 | 577 | 1 154 |
| 2 motors | 20 | 20 | 9 729 | 389 | 778 |
| 2 underground pipes | 20 | 30 | 24 300 | 851 | 1 701 |
| 2 above-ground pipes | 15 | 20 | 11 793 | 629 | 1 258 |
| 2 sprinkler systems | 15 | 25 | 1 049 300 | 7 465 | 14 930 |
| 2 cables | 20 | 15 | 8 700 | 370 | 740 |
| ONE 50 ha IRRIGATION SYSTEM | | | | | |
| 1 pump | 15 | 15 | 10 178 | 577 | 577 |
| 1 motor | 20 | 20 | 8 105 | 324 | 324 |
| 1 underground pipes | 20 | 30 | 20 560 | 720 | 720 |
| 1 above-ground pipes | 15 | 20 | 8 717 | 465 | 465 |
| 1 sprinkler system | 15 | 25 | 133 000 | 6 650 | 6 650 |
| 1 cable | 20 | 15 | 6 000 | 255 | 255 |

Table B2 *(continued)*

| MACHINERY EQUIPMENT | LIFETIME (YEARS) | SALVAGE (%) | LIST [1] PRICE | DEPRECIATION (PER UNIT) | TOTAL (R) |
|---|---|---|---|---|---|
| *ONE 30 ha DRAG LINE SYSTEM* | | | | | |
| 1 pump | 15 | 15 | 2 941 | 167 | 167 |
| 1 motor | 20 | 20 | 8 218 | 329 | 329 |
| 1 underground pipes | 20 | 30 | 24 484 | 857 | 857 |
| 1 above-ground pipes | 15 | 20 | 4 845 | 258 | 258 |
| 1 sprinkler system | 15 | 25 | 32 641 | 1 632 | 1 632 |
| **TOTAL DEPRECIATION ON MACHINERY AND IRRIGATION EQUIPMENT** | | | | | **140 439** |

1. Annual depreciation = (list price - salvage value)/expected lifetime. List price for machinery was obtained from the Guide to Machinery Cost (Department of Agriculture, 1993), the list price for irrigation equipment was obtained from AGRICO (PTY). LTD, Estcourt.

Table B3 Annual insurance paid for machinery, fixed assets and irrigation equipment for a representative 200 ha irrigation farm in the Winterton area, 1993

| ITEM | MARKET VALUE (R) | TYPE OF INSURANCE | INSURANCE PREMIUM (% OR R) | ANNUAL COST (R) |
|---|---|---|---|---|
| House | 200 000 | Comprehensive | 0,269 | 538 |
| Sheds | 80 000 | Comprehensive | 1,250 | 1 000 |
| 1 tractor (52 kW) | 8 000 | Comprehensive | 212 | 212 |
| 2 tractors (60 kW) | 10 000 | Comprehensive | 230 | 460 |
| 2 tractors (103 kW) | 38 000 | Comprehensive | 482 | 964 |
| 1 lorry (8 ton) | 33 000 | Comprehensive | 1 946 | 1 946 |
| 2 bakkies | 10 000 | Comprehensive | 1 156 | 2 312 |
| 1 harvester | 50 000 | Comprehensive | 1 304 | 1 304 |
| 2 60 ha centre pivots | 240 000 | Fire | 2,0 | 9 600 |
| 1 50 ha centre pivot | 200 000 | Fire | 2,0 | 4 000 |
| 1 drag line | 39 000 | Fire | 2,0 | 780 |
| **TOTAL INSURANCE COST PER ANNUM** | | | | **23 116** |

Table B4 Total annual interest paid on short-, medium- and long-term liabilities for a representative 200 ha irrigation farm in the Winterton area, 1993

| | VALUE/UNIT | TOTAL (R) |
|---|---|---|
| **A. SHORT-TERM ASSETS** | | |
| 1. Cash, insurance and investment | | 80 000 |
| 2. Livestock held for sale | | |
| 25 cull cows | 1 100 | 27 500 |
| 40 feedingpen steers | 1 300 | 52 000 |
| 16 feedingpen heifers | 1 200 | 19 200 |
| 60 speculation cattle | 1 100 | 66 000 |
| TOTAL SHORT-TERM ASSETS | | 244 700 |
| **B. MEDIUM-TERM ASSETS** | | |
| 1. Breeding herd | | |
| 4 bulls | 1 800 | 7 200 |
| 80 breeding cows | 1 200 | 96 000 |
| 20 replacement heifers | 1 000 | 20 000 |
| 2. Machinery | | |
| Tractors | | 104 000 |
| Implements | | 108 700 |
| Harvesters | | 50 000 |
| Lorries and trailers | | 57 000 |
| Bakkies | | 20 000 |
| 3. Irrigation equipment | | |
| 2 60 ha centre pivot system @ R4 000/ha | 240 000 | 480 000 |
| 1 50 ha centre pivot system @ R4 000/ha | 200 000 | 200 000 |
| 1 30 ha drag line system @ R1 300/ha | 39 000 | 39 000 |
| TOTAL MEDIUM-TERM ASSETS | | 1 181 900 |
| **C. LONG-TERM ASSETS** | | |
| 1. Farm and infrastructure | | 561 500 |
| TOTAL LONG-TERM ASSETS | | 561 500 |
| **TOTAL ASSETS** | | **1 988 100** |
| TOTAL LIABILITIES (debt-asset ratio = 40%) | | 795 240 |
| ANNUAL SHORT-TERM INTEREST PAID (40 % short-term liabilities @ 18% interest per year) | | 57 257 |
| ANNUAL MEDIUM-TERM INTEREST PAID (10 % medium-term liabilities @ 21% interest per year) | | 16 700 |
| ANNUAL LONG-TERM INTEREST PAID (50 % long-term liabilities @ 16% interest per year) | | 63 619 |
| **TOTAL INTEREST PAID ANNUALLY** | | **137 576** |

Table B5 Miscellaneous overhead expenses for a representative 200 ha irrigation farm in the Winterton area, 1993

| ITEM | ANNUAL COST (R) |
|---|---|
| **1. ELECTRICITY COST** | |
| 60 ha centre pivot systems | 2 822 |
| 50 ha centre pivot system | 1 411 |
| 30 ha drag line system | 940 |
| **2. WATER COST** (@ R180 per hectare) | |
| 60 ha centre pivot systems | 21 600 |
| 50 ha centre pivot system | 9 000 |
| 30 ha drag line system | 5 400 |
| **3. LABOUR** | |
| 30 labourers | 54 000 |
| **4. OTHER** | |
| Telephone, licenses, electricity, other | 5 000 |
| **TOTAL MISCELLANEOUS OVERHEAD COST** | **100 173** |

Table B6 Enterprise budget for dry-land maize, planted on 15 November in the Winterton area, 1993

| ITEM | UNIT | PRICE PER UNIT (R) | QUANTITY PER (ha) | VALUE PER ha (R) |
|---|---|---|---|---|
| **GROSS RECEIPTS** | | | | |
| Maize | ton | ----(1) | ----(2) | ----- |
| Maize stubble | ha | 35 | 1 | 35,00 |
| **TOTAL GROSS INCOME** | | | | ----- |
| **PRODUCTION COST** | | | | |
| Maize seed | kg | 5,10 | 13,3 | 67,83 |
| Fertilizer: DAP/KCL | kg | 1,025 | 150,0 | 153,75 |
| Nitrogen: urea | kg | 0,865 | 120,0 | 103,80 |
| Agric. lime | ton | 200,00 | 0,1 | 20,00 |
| Eptam | l | 21,86 | 4,0 | 87,44 |
| Robust | l | 17,26 | 2,5 | 43,15 |
| Atrazine | l | 9,90 | 2,0 | 19,80 |
| Spotaxe | l | 25,74 | 0,5 | 12,87 |
| Armo Blen | l | 36,94 | 0,18 | 6,46 |
| Benlate | kg | 80,35 | 1,0 | 40,18 |
| Insurance | R | 0,05 | 2 085,0 | 104,25 |
| Air spraying | ha | 23,65 | 1,0 | 23,65 |
| Harvesting cost | ton | 54,78 | ----(3) | ----- |
| Casual labour | days | 5,00 | 4,0 | 20,00 |
| Transportation 30 km | ton.km | 0,154 | 30x --(4) | ----- |
| Fuel and repairs | ha | 118,96 | 1,0 | 118,96 |
| Fixed labour | h | ----(5) | ----- | ----- |
| Interest | R | ----(5) | ----- | ----- |
| **TOTAL PRODUCTION COST** | | | | **822,14** |

1. Maize prices are stochastically varied.
2. Maize yields were simulated with the CERES crop-growth simulation model using 20 years' weather data.
3. Harvesting costs were calculated by multiplying the variable cost of the harvester (R/hour) by the harvesting speed (hours/ha), as obtained form Guide to Machinery Cost (Department of Agriculture, 1993) for the different simulated yields.
4. Transportation costs were calculated by multiplying the variable cost (R0,154/ton/km) by the 30 km and the simulated yield.
5. Fixed labour and interest costs were calculated under fixed cost.

Table B7 Enterprise budget for maize under irrigation, planted on 15 November in the Winterton area, 1993.

| ITEM | UNIT | PRICE PER UNIT (R) | QUANTITY PER (ha) | VALUE PER ha (R) |
|---|---|---|---|---|
| **GROSS RECEIPTS** | | | | |
| Maize | ton | -----(1) | -----(2) | ----- |
| Maize stubble | ha | 35 | 1 | 35,00 |
| **TOTAL GROSS INCOME** | | | | ----- |
| **PRODUCTION COST** | | | | |
| Maize seed | kg | 6,40 | 16,7 | 106,88 |
| Fertilizer: 2:3:2 (30) | kg | 0,93 | 235,0 | 217,38 |
| Nitrogen: urea | kg | 0,865 | 400,0 | 346,00 |
| Agric. lime | ton | 200,00 | 0,1 | 20,00 |
| Agric. gypsum | ton | 220,00 | 0,1 | 22,00 |
| Karate | l | 19,49 | 0,07 | 1,36 |
| Lasso | l | 14,76 | 5,0 | 73,80 |
| Atrazine | l | 9,90 | 2,0 | 19,80 |
| 2,4 D | l | 10,66 | 0,5 | 5,33 |
| Benlate | kg | 80,35 | 0,5 | 40,18 |
| Insurance | R | 0,05 | 3 336,0 | 166,80 |
| Air spraying | ha | 23,65 | 1,0 | 23,65 |
| Harvesting cost | ton | 54,78 | -----(3) | ----- |
| Casual labour | days | 6,00 | 6,0 | 36,00 |
| Transportation 30 km | km | 0,154 | 30x --(4) | ----- |
| Fuel and repairs | ha | 118,96 | 1,0 | 118,96 |
| Irrigation cost | mm | 0,64 | -----(6) | ---- |
| Fixed labour | h | -----(5) | ------ | ----- |
| Interest | R | -----(5) | ------ | ----- |
| **TOTAL PRODUCTION COST** | | | | **1 198,14** |

1. Maize prices are stochastically varied.
2. Maize yields were simulated with the CERES crop-growth simulation model using 20 years' weather data.
3. Harvesting costs were calculated by multiplying the variable cost of the harvester (R/hour) by the harvesting speed (hours/ha), as obtained form Guide to Machinery Cost (Department of Agriculture, 1993) for the different simulated yields.
4. Transportation cost was calculated by multiplying the variable cost (R0,154/ton/km) by 30 km and the simulated yield.
5. Fixed labour and interest costs were calculated under fixed cost.
6. Irrigation variable costs were calculated by multiplying the amount of water applied by a specific irrigation scheduling strategy (simulated by CERES) by a cost of 64 c/mm/ha.

Table B8 Enterprise budget for a 100 cow beef herd and 60 speculation cattle on a combination of grazing and kikuyu/ryegrass pastures in the Winterton area, 1993

| ITEM | UNIT | PRICE PER UNIT (R) | QUANTITY | DRESSED MASS (kg) | TOTAL VALUE (R) |
|---|---|---|---|---|---|
| **GROSS RECEIPTS** | | | | | |
| Steers | kg | -----(1) | 40 | 220 | ------ |
| Heifers | kg | ----- | 16 | 205 | ------ |
| Old cows | kg | ----- | 20 | 240 | ------ |
| Replacement heifers | kg | ----- | 5 | 225 | ------ |
| Speculation cattle | kg | ----- | 60 | 240 | ------ |
| Bulls | kg | ----- | 1 | 350 | ------ |
| Offals (hides) | year | 10 | 142 | ------ | 1420,00 |
| TOTAL GROSS INCOME | | | | | ------ |
| **PRODUCTION COST** | | | | | |
| Farm produced feed cost | | | | | |
| Kikuyu | ha | 899,41 | 30 | ------ | 26 982,30 |
| Ryegrass | ha | 1207,12 | 10 | ------ | 12 071,20 |
| Maize | ton | -----(2) | 64,8 | ------ | ------ |
| Maize stubble | ha | 35,00 | 100 | ------ | 3 500,00 |
| Purchased feed cost | | | | | |
| Summer lick | kg | 0,744 | 3976 | ------ | 2 958,29 |
| Winter lick | kg | 0,401 | 17202 | ------ | 6 898,00 |
| Autumn lick | kg | 0,470 | 3806,4 | ------ | 1 789,01 |
| Beefi quips | kg | 0,744 | 16200 | ------ | 12 052,80 |
| Speculation cattle | kg | -----(3) | 60 | 200 | ------ |
| Livestocks remedies : feedpen | year | 1 421,15 | 1 | ------ | 1 421,15 |
| Livestocks remedies : beef herd | year | 573,88 | 1 | ------ | 573,88 |
| AI | straw | 8,00 | 25 | ------ | 200,00 |
| Veterinary services | A.U. | 2,00 | 125 | ------ | 250,00 |
| Transportation | head | 10 | 142 | ------ | 1 420,00 |
| Marketing cost | year | -----(4) | ------ | ------ | ------ |
| Fixed labour | h | -----(5) | ------ | ------ | ------ |
| Interest | R | -----(5) | ------ | ------ | ------ |
| **TOTAL PRODUCTION COST** | | | | | **70 116,63** |

1. Maize prices are stochastically varied.
2. Maize was included on a production cost basis; *e.g.*, 64,8 tons of maize were withdrawn from the maize enterprise.
3. It was assumed that purchasing prices for speculation cattle would be 10% less than the price that the farmer would obtain after fattening.
4. Marketing cost was calculated as 5 % of the gross receipts for cattle sales.
5. Fixed labour and interest were calculated as an overhead cost.

Table B9 Enterprise budget for 100 head of speculation cattle on maize stubble in the Winterton area, 1993

| ITEM | UNIT | PRICE PER UNIT (R) | QUANTITY | DRESSED MASS (kg) | TOTAL VALUE (R) |
|---|---|---|---|---|---|
| **GROSS RECEIPTS** | | | | | |
| Speculation cattle | kg | -----(1) | 100 | 230 | ------ |
| Offals (hides) | year | 10 | 100 | ---- | 1 000,00 |
| TOTAL GROSS INCOME | | | | | ------ |
| **PRODUCTION COST** | | | | | |
| Farm produced feed | | | | | |
| Maize stubble | ha | 35,00 | 100 | ------ | 3 500,00 |
| Purchased feed cost | | | | | |
| Summer lick | kg | 0,744 | 372,00 | ------ | 276,77 |
| Winter lick | kg | 0,401 | 9 200,00 | ----- | 3 689,20 |
| Speculation cattle | kg | -----(2) | 100 | 200 | ------ |
| Dip | ml | 0,111 | 675 | ------ | 74,93 |
| Transportation | head | 10 | 100 | ------ | 1 000,00 |
| Marketing cost | year | -----(3) | ----- | ------ | ------ |
| Fixed labour | h | -----(4) | ----- | ------ | ------ |
| Interest | R | -----(4) | ----- | ------ | ------ |
| **TOTAL PRODUCTION COST** | | | | | **8 540,90** |

1. Maize prices are stochastically varied.
2. It was assumed that purchasing prices for speculation cattle would be 10 % less than the price that the farmer would obtain after fattening.
3. Marketing cost was calculated as 5 % of the gross receipts obtained for the cattle.
4. Fixed labour and interest were calculated as overhead cost.

## PRICE RISK FOR BEEF PRODUCTION

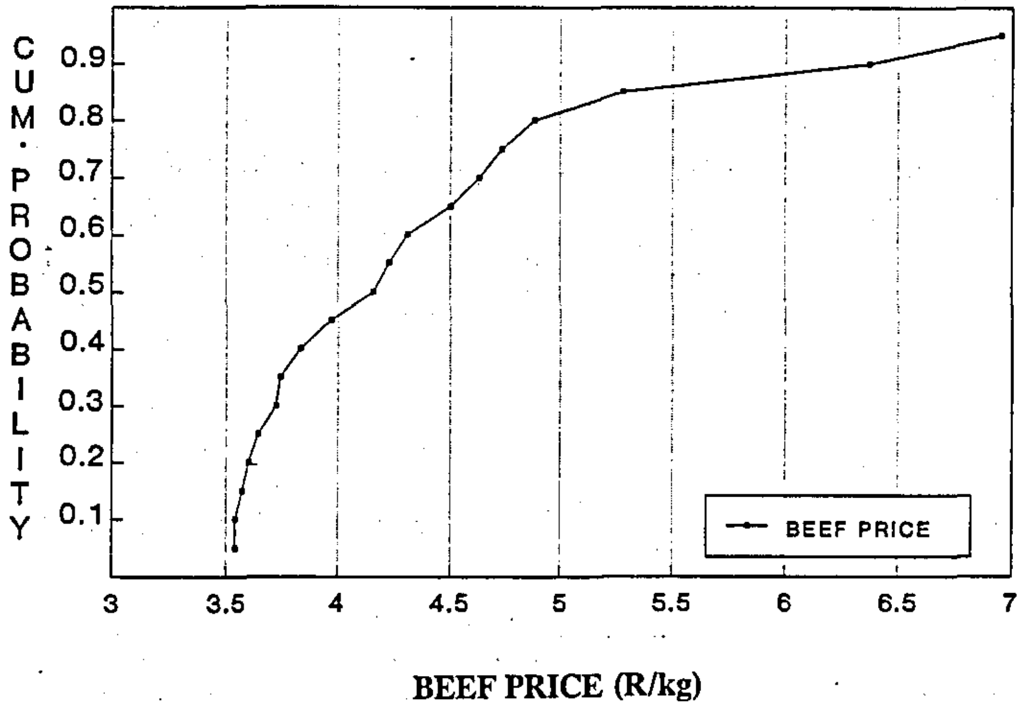


Figure B1 Cumulative distribution function of the producer price for beef which was elicited subjectively from beef farmers in the Winterton area, 1993

## PRICE RISK FOR MAIZE PRODUCTION

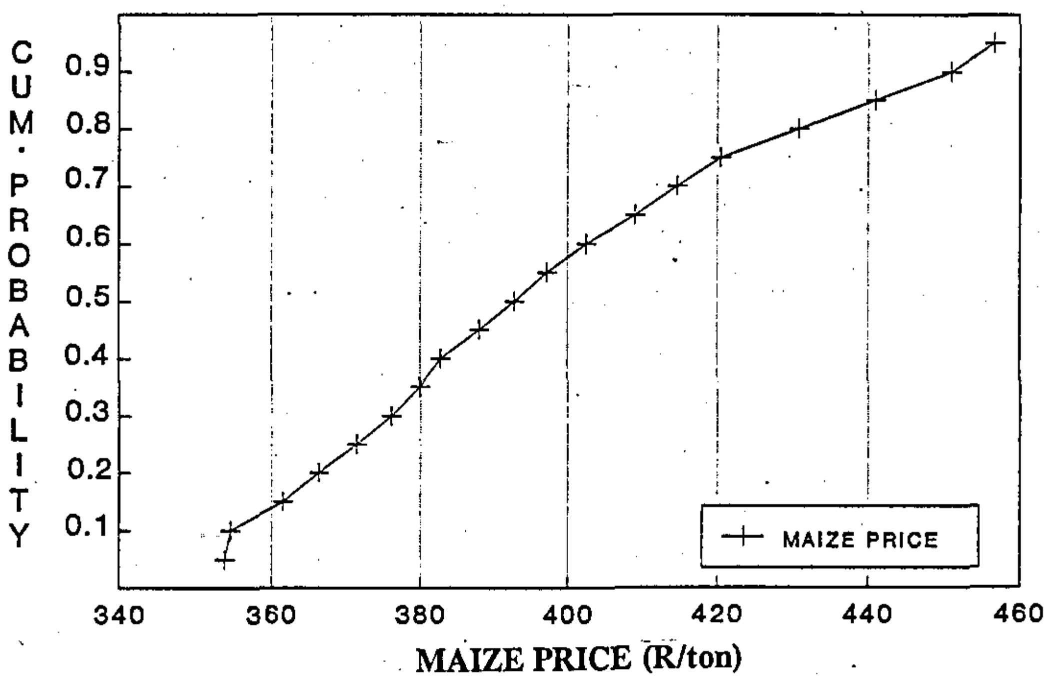


Figure B2 Cumulative distribution function of the producer price for maize in South Africa, as formulated by Meiring, 1993

# APPENDIX C

## RESEARCH RESULTS OF THE VALUE OF INFORMATION ON THE HUTTON SOIL

Table C1 Expected maize yields (kg/ha) and the associated irrigation water applied (mm/ha) by the identified information strategies, as optimized by the SIMCOM model, on Hutton soil (PESW=138 mm) under unlimited and limited water supply conditions for risk-seeking, risk-neutral and risk-averse decision makers, respectively for the Winterton area with a long-term average rainfall of 674 mm/year

| HUTTON | UNLIMITED WATER | | | LIMITED WATER | | |
|---|---|---|---|---|---|---|
| SOIL | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING | NEUTRAL | AVERSE | SEEKING | NEUTRAL | AVERSE |
| Strategy 1 | | | | | | |
| Yield (kg/ha) | 9 672 | 9 672 | 9 672 | 9 021 | 9 021 | 9 021 |
| Water (kg/ha) | 306 | 306 | 306 | 148 | 148 | 148 |
| Strategy 2 | | | | | | |
| Yield (kg/ha) | 9 669 | 9 693 | 9 749 | 9 401 | 9 416 | 9 360 |
| Water (mm/ha) | 151 | 153 | 213 | 129 | 129 | 133 |
| Strategy 3 | | | | | | |
| Yield (kg/ha) | 9 513 | 9 710 | 9 747 | 9 386 | 9 461 | 9 372 |
| Water (mm/ha) | 131 | 168 | 212 | 118 | 128 | 114 |
| Strategy 4 | | | | | | |
| Yield (kg/ha) | 9 304 | 9 680 | 9 751 | 9 274 | 9 470 | 9 265 |
| Water (mm/ha) | 104 | 141 | 220 | 103 | 117 | 100 |
| Strategy 5 | | | | | | |
| Yield (kg/ha) | 9 333 | 9 708 | 9 734 | 8 313 | 9 491 | 9 285 |
| Water (mm/ha) | 101 | 153 | 208 | 84 | 118 | 94 |
| Strategy 6 | | | | | | |
| Yield (kg/ha) | 9 476 | 9 726 | 9 748 | 9 373 | 9 458 | 9 538 |
| Water (mm/ha) | 118 | 153 | 178 | 113 | 115 | 107 |

Table C2 Sensitivity analysis of the effect of moderate risk preferences (RAC = ±0,00005) on the value of perfect soil-water information (Strategy 4) on Hutton soil (PESW=138 mm) in the Winterton area, 1993

| STRATEGY 4 ON HUTTON SOIL | UNLIMITED WATER | | LIMITED WATER | |
|---|---|---|---|---|
| | RISK PREFERENCES | | RISK PREFERENCES | |
| | SEEKING (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | AVERSE (R/ha) |
| RAC = ±0,0001 | 141 | 311 | 230 | 320 |
| RAC = ±0,00005 | 143 | 288 | 230 | 262 |

Table C3 The effect of perfectly negatively correlated yield and product prices on the value of perfect soil-water information (Strategy 4) on Hutton soil (PESW=138 mm) in the Winterton area, 1993

| STRATEGY 4 ON HUTTON SOIL | UNLIMITED WATER | | | LIMITED WATER | | |
|---|---|---|---|---|---|---|
| | RISK PREFERENCES | | | RISK PREFERENCES | | |
| | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) | SEEKING (R/ha) | NEUTRAL (R/ha) | AVERSE (R/ha) |
| Correlation = 0 | 141 | 128 | 311 | 230 | 196 | 320 |
| Correlation = -1 | 192 | 134 | 202 | 80 | 218 | 313 |