Report to the Water Research Commission

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INCREASING THE ECONOMIC EFFICIENCY OF WATER AND ENERGY USE FOR IRRIGATION AT WHOLE FARM LEVEL IN CENTRAL RSA, TAKING RISK INTO ACCOUNT

VOLUME I

by

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Signed:

LK OOSTHUIZEN
PROFESSOR and PROJECT LEADER

FOREWORD

LK Oosthuizen

FOREWORD

The purpose of this foreword is to inform the reader concerning the three volumes in which the research on ***Increasing economic efficiency of water and energy use for irrigation at whole farm level in central RSA*** was published.

Volume I, entitled ***Development of a decision support system for increasing the economic efficiency of water and energy use for irrigation at whole farm level in central RSA, taking risk into account***, comprises the executive summary of the total project, as well as the summaries of the research that are reported in Volumes II and III.

Volume II comprises the research done in the Winterton area on the development of procedures to determine the value of irrigation scheduling information. The title of Volume II is ***Increasing economic efficiency of water and energy use for irrigation at whole farm level in the Winterton area.***

Volume III comprises the research done in the Vanderkloof Dam area (previously PK le Roux Dam) on the development of a decision support system for the evaluation of risk management at farm level. This volume is in Afrikaans and is entitled, ***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 name changes of dams and canals in the three volumes are dealt with in the following manner. Volume I uses the new names with an indication of the former names. Volumes II and III contain maps with the former names that were left unchanged, due to cost implications, but the changes in the text are indicated with footnotes.

Lastly, different compiling authors worked on the three volumes, according to their respective contributions.

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EXECUTIVE SUMMARY

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INCREASING THE ECONOMIC EFFICIENCY OF WATER AND ENERGY USE FOR IRRIGATION AT WHOLE FARM LEVEL IN CENTRAL RSA, TAKING RISK INTO ACCOUNT

BACKGROUND AND MOTIVATION

The present research on increasing the economic efficiency of water and energy use in irrigation farming, builds on the previous project of the Water Research Commission ***Economic evaluation of alternative irrigation scheduling strategies for wheat in the irrigation area of the Free State Region***. In the latter project, methods and instruments were developed and illustrated for the economic evaluation of irrigation efficiency at enterprise level. Justice would not have been done to the qualitative and quantitative value of this research, if these methods and instruments were not developed further to improve the economic efficiency of irrigation at whole farm level. It was essential to expand this study at enterprise level to whole farm level in order to be able to include the possibility of crop substitution allowing for risk, and the scheduling of water, allowing for the value of information, when taking into account limited water supplies and higher energy costs at whole farm level.

Where it was indicated that an investment in centre pivot irrigation with a system of crop rotation of wheat, maize and cotton is profitable in the long-term, analyses ought to be expanded, not only to evaluate the influence of other crop-rotation systems, but also to determine overhead variables like the influence of liability ratios and financing methods, on business profitability. By expanding the research on the advantages of improved irrigation scheduling to the whole farm framework, the value of improved soil and weather information for irrigation farmers, can be determined.

This research also linked up logically with existing research projects in agricultural water management in the Faculty of Agriculture at the UOFS and utilized the inputs of researchers in the Departments of Agricultural Meteorology, Agricultural Engineering, Soil Science, Agronomy and Agricultural Economics. The inter-disciplinary facets referred to, are the results of irrigation efficiency at farm and scheme level.

The major research problem in this study, was the lack of useful analyzing instruments to evaluate the economic efficiency of water and energy use for irrigation at whole farm level, taking into account the dynamic environment in which irrigation takes place, as well as the attitudes of farmers towards risk. Research done in this study can therefore make substantial contributions at micro- as well as on macro level to improve the efficiency of agricultural water and energy use.

OBJECTIVES

The main goal of the research was the development of methodologies to analyze and improve the economic efficiency of water and energy use in typical farming systems (combination of enterprises) in humid and semi-arid areas under centre pivot irrigation at whole farm level, taking into account the dynamic environment in which irrigation occurs, as well as the attitudes of farmers towards risk.

The specific objectives as stated in the original project proposal, were as follows:

(a) To estimate the water requirements and yield levels of wheat, maize, cotton, peanuts and lucerne in soils with low, average and high profile available water capacities in semi-arid and humid areas with the aid of crop-growth simulation models.

(b) To identify the most important sources of risk and risk-management strategies for typical farming systems in humid and semi-arid areas, on the one hand, and to apply the interval method in measuring the risk preferences of farmers and evaluate risk-management strategies on the other hand.

(c) To estimate the annual cost of typical farming systems in semi-arid and humid areas under full and supplementary irrigation, as well as under dry-land conditions.

(d) To illustrate a methodology to determine the effect of improved water and weather information on expected income, considering the important features of the economic environment, the whole farm and the irrigation farmers (variable prices and non-neutral risk preferences).

(e) To determine the effects of alternative pumping restriction scenarios on the expected income, taking into account variable pump capacities, profile available water capacities of soils, irrigation-scheduling strategies and risk preferences of irrigation farmers.

(f) To develop decision support systems to improve water and energy use at farm level, as well as to expand the literature data base on irrigation economics.

Research to obtain the above-mentioned objectives was carried out in central RSA in two irrigation areas, *i.e.* the irrigation area with water provision from the Vanderkloof Dam (previously PK le Roux Dam) and the Winterton irrigation area. The first area comprises the Vanderkloof State Water Scheme, the area on either side of the Orange-Riet Canal (previously Sarel Hayward Canal) and the irrigation on the Cape bank of the Orange River between Vanderkloof Dam and Hopetown. Irrigation development which occurred here since 1977, covers almost 20 000 ha which are mainly irrigated by centre pivot systems. In the Winterton area approximately 7 000 ha are irrigated by approximately 100 land owners.

In the research, data were collected by different means. In both areas an initial mail questionnaire was later followed up by questionnaires which were completed during personal interviews with farmers. Farmers and experts were involved throughout the process by means of group discussions carried out in the research areas. Further important sources of data were organizations who supplied secondary data.

A first step in the research was to define and apply a procedure to identify representative farms for the research areas. Data were obtained by means of mail questionnaires and group discussions, as well as from secondary sources. Representative farms were constructed on the basis of each area's fixed-resource situations, variable resources and the capital structures of farmers in the areas. These representative farms were used throughout the research as basis for further economic analyses at whole farm level. This ensured that results were reliable and applicable to farmers in the area.

The risk attitudes of irrigation farmers in both areas were also empirically determined. This aspect of the research builds on the basis that was set in the previous project. With information on the risk preferences of farmers in the respective areas, the value of information and preferences strategies for specific groups of decision makers could be empirically determined.

In the Vanderkloof Dam area the present research mainly focussed on determining the importance of alternative risk sources and management responses, formulating risk-management strategies and developing a decision support system for the evaluation of risk management. Research in the Winterton area comprised the development of a procedure to calculate the value of irrigation information, which included a model to optimize irrigation management decisions. The influence of pumping restrictions on irrigation efficiency was evaluated, emphasizing the possible advantage of ESKOM'S time-of-use electricity option.

The above-mentioned main components of the research were, however, only made possible by various research activities which collectively contributed to the development and illustration of procedures and instruments to evaluate the analysis and enhancement of the economic efficiency of water and energy use at whole farm level.

This report of results is presented in three volumes. Volume I contains the executive summary as well as the summaries of volume II and III. Volume II comprises six chapters on the research in the Winterton area, while Volume III comprises six chapters on the research results in the Vanderkloof Dam area. The extent and especially the nature of the research results necessitates dividing the work in three volumes to present the research objectives in a meaningful way.

RESULTS AND CONCLUSIONS

1. A procedure to develop representative farms was developed and implemented to ensure that economic analyses could be executed at whole farm level. This procedure was implemented in both the Vanderkloof Dam area and the Winterton area. The results and the applicability thereof indicated the value of this procedure as an aid to economic analyses at micro level as well as for the evaluation of the impact of policy decisions at farm level.
2. The perceptions of irrigation farmers regarding the importance of risk sources and ways to manage risks, were determined. The risk of variable producers' prices and risks pertaining to climate, were viewed as the most important risk sources, while debt management was viewed as the most important way to counteract risk. These results corresponded with findings in USA studies and formed a basis for the formulation of alternative risk-management strategies. These results also directed the manner of risk simulation in the development of decision support systems.
3. A decision support system consisting of three modules, was developed and surmounted the problem of lack of aids for practical and timely support to risk management at farm level. This comprehensive system which can be used in a wide variety of farming situations, can also make a substantial contribution to extension and research.
4. In both research areas, farmers' risk preferences varied from risk-seeking to risk-neutral with more of the Vanderkloof Dam farmers in the extreme categories. These

results indicated that policy makers must consider such preference differences in the successful implementation of alternative management strategies. Farmers in the Winterton area tended to be more risk-averse towards wealth risk than towards annual income risk.

5. The illustration of the procedures and instruments developed in this research, resulted in informative empirical results. From a risk-management viewpoint, the maintenance of different levels of fixed liabilities had the most important results, with only a debt:asset ratio of 30 % which could be viewed as safe for farmers in the area. Doubling of the irrigation area from 60 to 120 ha meant a cash flow advantage for farmers. Preferential crop-rotation systems in the Vanderkloof Dam area included wheat and lucerne as well as either lucerne or maize. The choice of ensurance against hail was influenced by the particular crop-rotation system. Although no-insurance increased the total risk at farm level, risk-seeking farmers in the area did not ensure against hail. The incorporation of a mutton sheep enterprise in the Vanderkloof Dam area was also dependent on the farmers' risk preferences. Because livestock enterprises already became risky with a debt:asset ratio of 30 %, risk-averse farmers preferred to practise irrigation only.

6. The research also determined that the two maize crop-growth simulation models IBSNAT and PUTU irrigation, seemed suitable to analyze the economics of crop production under diverse production conditions in South Africa. The results show that risk preferences could influence the selection of a crop model.

7. An irrigation, economic and crop-growth simulation model as well as an efficient search procedure and optimizing model, were successfully linked and used to evaluate the role of information for an irrigation farm under conditions of limited and unlimited water supply. The use of the dynamic model indicated that more sophisticated irrigation information could increase the expected net returns due to the attainment of near maximum yields with simultaneous saving on irrigation water use. Results further indicated that specific soil information could account for between 97 and 99 % of the returns generated by information strategies using future weather information. The results prove that information is a partial substitute for soil quality and water availability. The maximum amount that irrigation farmers in the Winterton area without water restrictions could pay for the best information, varied between R136/ha and R330/ha, depending on their risk preferences. With water shortages, this value increased with at least 49 %. Thus the detrimental results of limited water were to a large extent decreased by better information.

8. Pumping restrictions influenced both yields and the amount of water used for irrigation. The average maize yield decreased but the average amount of water

administered when pumping time was restricted, increased because irrigation commenced at higher soil-water levels. These results were, however, dependent upon the soil type and the capacity of the system. Such a strategy can therefore only become profitable if reductions in the cost of electricity are made possible as is the case with the Ruraflex option which supplies cheaper electricity outside peak hours.

ACHIEVEMENT OF RESEARCH OBJECTIVES AND VALUE OF RESULTS

The objectives set in this research, were achieved to a satisfactory extent. Each of these objectives is referred to briefly in chronological order.

Firstly, the most important crops in both areas (Winterton and Vanderkloof Dam) were identified and wheat, maize, cotton, soybeans and lucerne were included. As a result of the requirements of further economic analyses, attention was not only given to water needs and yield levels of crops, but also to cultivation practices and production costs and to the risk involved with each crop in terms of price and yield variability. Information for this purpose was obtained by using crop-growth simulation models as set out in the project objective, but also by means of group discussions and from other secondary sources. Although much of the data obtained in this fashion, were intermediate in the achievement of the other objectives, important and useful results which need mentioning were obtained. Enterprise budgets for crops in both areas were compiled and can be used as a basis for economic analyses. Important work was also done with regard to testing of crop-growth models from an agricultural-economic viewpoint. This entailed the specification of a procedure as well as a comparison of the models.

The second objective was achieved by means of personal interviews in the research areas to measure the risk preferences of irrigation farmers, as well as their perceptions with regard to the importance of alternative risk sources and management strategies. Information on risk preferences which previously had been unobtainable locally, was obtained and this enabled the research team to determine the value of information and preference strategies for decision makers with different risk preferences. Once information on farmers' perceptions on risk sources and risk-management strategies was obtained, risk modelling could be done and risk-management strategies were formulated.

The annual cost of representative farming systems at whole farm level, was estimated. This was made possible by extending procedures at enterprise level to farm level where all overhead variables were taken into account. Procedures were developed to be as flexible as possible in order to handle various situations.

A methodology was illustrated where the value of information was determined by successfully linking irrigation, economic and crop-growth simulation models with an optimizing model. This dynamic model (SIMCOM) took all the important variables into account and could enhance irrigation management through simulation of situations which occur in practice. The greatest advantage of this procedure is the fact that optimal solutions can be identified by linking with the optimization model.

The effects of pumping restriction scenarios were determined by using the SIMCOM model, given the Ruraflex electricity option where the cost of electricity is less during certain hours of the day. Profitability was adversely affected by pumping restrictions when pump capacities were restrictive and profile available water capacities of soils decreased. These results are important from a policy viewpoint, because the amount of compensation necessary to pump water during certain hours only, can be ascertained.

Because the main objective of this research was to develop methodologies, procedures and facilities to analyze and improve water and energy use, decision support models logically resulted from this. The SIMCOM model, used to determine the value of information, is an example of such a model. A decision support model was also developed for the evaluation of risk management at whole farm level. This model, consisting of three modules, calculated all costs and income at enterprise level as well as farm level. Risks with regard to crop prices and yield, interest rates and possible hail damage were also fully simulated. Irrigation management, including water and energy use, can therefore be promoted.

The literature data base on the economics of irrigation was extended to 1 763 sources.

FURTHER RESEARCH PROPOSALS

Further research proposals can be made, because during this research, certain fields were identified which received little or no attention, and other facets were too extensive to be addressed in this study.

The previous research project was executed at enterprise level. This research was expanded to whole farm level. A logical expansion will be to further develop the methodology and procedures/aids for use at regional level. In this way a set of instruments will be created for the support of irrigation management from micro- to macro level extending from the farmer to the policy maker.

More specifically research can be done in the following fields:

1. Further investigations can be made into the risk preferences of farmers, especially the difference between income and wealth risk preferences. The verification of the hypothetical options of the interval method may also be important.
2. With the determination of the value of irrigation information on an annual basis, the possibility of a learning process was excluded. Further expansions can be made to determine the value of information on a real-time and multi-year basis. The value of information obtained in this research can also be verified with other methods.
3. Because this study concentrated on the development of procedures and methods, the empirical applications thereof are not comprehensive. Therefore much practical research can ensue from this. Thus the concept of representative farms may also be applied in other areas. Apart from the fact that the value of information for other farm firms can be determined, the influence of enterprise options, farm size and other economic variables on the value of information can be determined. The decision support system with regard to risk management, inevitably offers almost unlimited implementation possibilities. This varies from enterprise level problems like the selection of mechanization systems, cultivation methods, water allocation, labour needs and enterprise options to problems at farm level like the selection of financing methods, the feasibility of further irrigation and other investments, the influence of overhead variables and the consequences of land purchasing or land leasing.
4. The inclusion of risk in farm level analyses made an entire research field more accessible. The determination and analysis of the influence of subjective probabilities as a means of quantifying risk, can be done. Probability distributions must be determined for the most important variables. The real influence of production and price risk can also be simulated at farm level and risk-management strategies can thus be identified and analyzed.
5. The implementation possibilities of this decision support system, justifies further development of the system. As a first step, to make general use of the system possible, all three modules ought to be programmed in computer language. This will eliminate dependence on a spread sheet program. A second step is to use this system as a basis and develop it as a model that will be able to support management decision-

making taking risk into account, also in the long term. As is the case with any computer program, putting this program into practice will identify opportunities to improve it.

6. This study made it clear that more attention will also have to be given to the decision maker. Questions like the following arise from an information view point: Is information optimally utilized by decision makers? What management needs exist to implement and carry out a better-information strategy? Risk management, as an integral part of farm management, ought to be promoted by encouraging managers to view economic variables as probability distributions that ought to be managed. Although the decision support systems that were developed in this study contribute to this, utilization of such a system will be determined by the relevancy and the value of the information it supplies, as well as by its user friendliness. If the expected value of the information exceeds the cost and effort of acquisition, such a system will contribute to better decision making. Because the system that was developed can supply valuable information for decision making, this system ought to be used to improve risk management.

SUMMARY OF VOLUME II

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

LK Oosthuizen, JHF Botes, DJ Bosch and P Breytenbach

INTRODUCTION

The focus of this part of the 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 results. 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 area, 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 areas 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 areas 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 areas 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 preferences 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.

SUMMARY OF VOLUME III

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR THE ECONOMIC EVALUATION OF RISK MANAGEMENT AT FARM LEVEL AND THE APPLICATION THEREOF IN THE SEMI-ARID REGION BELOW THE VANDERKLOOFDAM

JA Meiring and LK Oosthuizen

INTRODUCTION

The increase in risk at farm level demands that risk management should form an integral part of the daily process of managing a farm business. Risk management at farm level however, is subject to constraints, firstly, because of a lack of analysis techniques that might enable one to take risk into account in decision making, and, secondly, because of the level of sophistication and cost of the aids that are in fact available. This research was motivated by the fact that risk management on South African farms is currently constrained by a lack of instruments and aids that would render it possible to take risk explicitly and practically into account in analyses at farm level.

The principal goal of this part of the research was to develop models that would serve to support risk management at enterprise as well as whole farm level. The goal was to develop practical and flexible models that would ensure wide applicability. Creation of such models as a decision support system will facilitate, improve and expedite risk management. It was decided that in order to accommodate the nature of decision making at farm level, three complementary models needed to be developed to support short-term decision making. The first model was to be of a deterministic nature and capable of calculating income and costs at enterprise level, enabling it to support enterprise, mechanization and labour management. Secondly, support at enterprise level could be extended by means of a second model that would render it possible to take risk into account. As a third component of a suitable system, overhead variables could be included to support decision making at whole farm level.

A second goal was to employ all three modules to evaluate irrigation farming below the Vanderkloof Dam (previously PK le Roux Dam). In this way the potential applications of the model could be demonstrated, while at the same time results would be generated which could be used as decision-making guidelines by farmers in the research area. Three objectives were set with a view to realizing the second goal of the research. The first of these was to identify representative farm businesses in the Vanderkloof Dam area. The second objective was to determine the perceptions of the farmers concerning the importance of different sources of risk and management behaviour involving risk. The third objective was empirical measurement of farmers' attitudes towards risk.

Since research at enterprise level had already been carried out in the irrigation area below the Vanderkloof Dam, the choice of this area as field of research held the advantage of the researchers being able to build on existing knowledge and experience. Irrigation farming also makes higher demands on the flexibility of such a model. Three localities, *i.e.* the Vanderkloof Government Water Scheme, the area on both sides of the Orange-Riet Canal (previously Sarel Hayward Canal) and the irrigation area on the Cape Province banks of the Orange River from the Vanderkloof Dam to Hopetown were used for the practical part of the research. The Vanderkloof Dam, with a storage capacity of 3 237 million cubic metres, is the most important source of water supply in this area. At present only a small part of the area is under irrigation, but it would be possible to extend irrigation to good agricultural soil at higher-lying levels. Alongside the river the soil area is relatively sloping and accordingly centre pivot irrigation is mainly used. Soil types such as Hutton, Clovelley and Oakleaf are irrigated. Approximately 19 642 ha are irrigated in the three localities. Run-off of irrigation water and crust formation are management problems commonly experienced by irrigation farmers. Most of the veld in this area consists of False Upper Karoo.

This irrigation area is connected to Bloemfontein and Kimberley by good tarred roads and to De Aar by rail. Farmers in the area are served by two co-operatives, as well as a cotton gin at Modder River. The first irrigation farmers started to develop their farms in 1977. Development by the Government under the Vanderkloof Government Water Project was followed by private development on the Cape bank of the Orange River.

The empirical part of the research was wholly conducted in these irrigation areas, and development and evaluation of computer models formed the most important component of the research. Other research methods employed included the holding of group discussions, the use of mail questionnaires and structured interviews with farmers in the area. Secondary financial and insurance data were also obtained from organizations involved in irrigation farming.

Volume III of the report follows on Volume II and consists of six chapters, as well as an introduction and a summary. Chapters 1 to 6 each constitutes a separate entity, but they are also building-blocks of the total research. The three components of the total decision support system that was developed, are presented and applied in Chapters 3 to 5. Chapters 1, 2 and 6 contain an exposition of research conducted to support the development and implementation of the total decision support system.

THE FORMULATION OF REPRESENTATIVE FARM BUSINESSES FOR THE AREA BELOW THE VANDERKLOOF DAM

Application of the research done for the purpose of this report to representative farms held the advantage of enabling certain farmers in the research area to implement the results. Since the representative farms displayed diverse characteristics, they also provided an opportunity to test the flexibility of the developed models. At the micro level the representative farms also offered an opportunity to evaluate the impact of economic and technical variables at whole farm level. This approach might result in savings in respect of research resources and render it possible to apply the research to a larger group of farm businesses.

Although representative farms have often been used in local agricultural-economic research, doubt existed as to the *modus operandi* that should be followed in formulating representative farms. Only a clearly defined and commonly applied procedure would render it possible to compare the representative farms of different studies with one another. Accordingly the use of representative farms (RFs) in agricultural-economic research was analyzed. The concept of a representative farm was defined, and on the basis thereof a procedure for identifying representative farms in the irrigation area was recommended and implemented.

The concept of typical farms has been used since the twenties. In local studies a typical farm was identified as the most common type of farm situation encountered in a relatively homogeneous geographic area or one that applied to a group of farmers. Representative farms have been used in research at macro- as well as micro level. The purpose for which RFs are formulated inevitably has an influence on the formulation procedure. A variety of physical and financial variables can be used as criteria for distinguishing between different RFs, but the number has to be limited. Data reliability serves to indicate the best way of collecting such data. RFs also do not reflect an average situation.

Since RFs for the research area would also be formulated with a view to evaluating risk-management strategies, it had be done in such a way that the results would apply to as many farms in the research area as possible. An RF was accordingly defined as a resource situation with which a reasonable number of farmers could identify themselves and which differed from other resource situations to the extent that the differences yielded different economic and financial results. On the basis of this definition a four-step procedure was followed to develop representative farms for the area. Firstly, the fixed-resource situation in the area was identified. Secondly, the nature and level of variable resources that were dependent on the fixed resources were determined. Thirdly, the liability structure typically encountered in the area was analyzed. The last step was to identify management strategies for each RF.

A mail questionnaire containing nine questions was compiled and sent to 95 irrigation farmers with a view to determining the fixed-resource situation in the irrigation area. A response rate of 91 % was realized. The data were analyzed statistically by computer and processed through the compilation of frequency distributions. The variables, irrigation soil area, grazing area, as well as type of irrigation and livestock, were used to identify six fixed-resource situations.

Since variable resources are dependent on fixed resources, information regarding the variable resources of producers who fell within the specified fixed-resource situation, was obtained by means of group discussions. A questionnaire was used as a basis for collecting data on crops, number of livestock, type and number of implements, labour, as well as economic and technical coefficients of the mechanization system.

For the purpose of identifying the typical capital structure of farmers in the research area, anonymous balance-sheet information was obtained from co-operatives. Frequency distributions were compiled and on the basis of these three debt:asset ratios were identified as typical.

The above-mentioned procedure resulted in the formulation of six representative farms for the research area, of which three included 60 ha under irrigation and the other three 120 ha. Each of these areas was also combined with no grazing, 500 ha of grazing or 2 500 ha of grazing respectively. The 60 ha RFs are irrigated by means of a centre pivot system, while in the case of the 120 ha RFs, 108 ha are irrigated by means of the centre pivot system and the remaining 12 ha by means of drag lines. The grazing is utilized by a mutton-sheep enterprise. Typically 18 implements are required to cultivate the 60 ha of irrigation soil and 23 implements in the case of the 120 ha. The market value of the two mechanization systems amounts to R145 700 and R203 800 respectively. The 60 ha RFs employ three permanent labourers and the 120 ha RFs five. The sheep enterprise on 500 ha grazing includes

160 ewes, while the number of ewes increases to 650 on the 2 500 ha of grazing land. The lambing and weaning percentages are higher in the case of the larger livestock enterprises. In both instances the livestock enterprises function independently from the irrigation.

The farmers were divided into three groups on the basis of their capital structure, namely farmers with 30, 50 and 70 % debt:asset ratios respectively. In general there are no medium-term liabilities. Borrowed capital consists of 30 % short-term and 70 % long-term liabilities. Ninety per cent of the short-term liabilities takes the form of a bank overdraft and 10 % is represented by money owed to the co-operative.

Formulation of the representative farms was done in two steps. Firstly, representative farms were defined and three of the steps in the four-step procedure for formulating representative farms were illustrated. The advantage of such a uniform procedure is that it renders it possible to compare RFs in different regions and identify changes within the same area over time. Secondly, six representative farms were identified for the research area, each with its fixed-resource situation as well as variable resources. This procedure also provided for the determining of the typical debt:asset ratios. This, in short, implied that six sets of economic and physical data for six different farms that are representative of the type of farms in the region were available for the purpose of implementing alternative risk-management strategies and economic analysis. Results obtained in such a manner have wider application possibilities than results obtained by means of case studies or by using average values.

RISK PERCEPTIONS AND RISK-MANAGEMENT STRATEGIES FOR THE IRRIGATION AREA BELOW THE VANDERKLOOF DAM

The nature and importance of risk demand a comprehensive approach involving aspects such as identifying the sources of risk, measurement of risk, attitudes towards risk and risk management as an integral part of risk analyses. The representative farms and their accompanying data included no information concerning the nature, extent and importance of risk in the research area. Collection of data on how farmers experience risk as well as their perceptions of various management approaches therefore constituted a logical point of departure for the analysis of risk at farm level. Information on the perceptions of farmers in the research area concerning risk and the importance of management action to counteract risk was regarded as essential supplementary information for formulating relevant risk-management strategies for the area. Knowledge of the importance of different sources of risk was considered to hold the further advantage of rendering it possible to contribute constructively towards risk modelling. The purpose of this part of the research was therefore to determine the perceptions of irrigation farmers below the Vanderkloof Dam concerning the importance of sources of risk and risk-management strategies and to identify specific risk-management strategies on the basis of the results.

For the purpose of this research, risk is regarded to be present in situations where the results of decisions are not yet known during the decision-making process. Risk management comprises a choice between alternative actions that might effect a change in respect of exposure to the financial results of uncertain farming income.

Since 1983 various American studies have been conducted to determine farmers' risk perceptions and viewpoints regarding risk-management strategies. Recently similar studies have been conducted in this country, but not in respect of irrigation farmers. In all of these studies a questionnaire was used listing sources of risk and risk-management strategies, with the request that the respondents should indicate the importance of each source or action on a four- or five-point scale. In most cases the price obtained for products and weather or rainfall variability, thus also yield variation, were indicated as the most important risk sources. On the other hand, debt management and diversification were found to be regarded as the most important risk-management strategies. The general use of a questionnaire is indicative of its merit as a research technique. The nature of a farm business, as well as its locality has an influence on the importance of risk sources. Risk-management strategies that have been utilized to good effect are often regarded as important.

The questionnaire used in the above-mentioned studies was also used for the current research with a few adjustments. In the case of crop production 21 sources of risk were listed in the questionnaire, and in the case of livestock production 19. Twenty-three risk-management strategies were also included. The questionnaire was completed during personal interviews conducted with 65 farmers in the research area. The importance of the risk sources was determined by arranging them according to the average values obtained on the five-point scale. The same procedure was followed concerning management strategies. The link between a farmer's perceptions and socioeconomic factors, such as age, irrigation and grazing area and debt burden, was established. A test was applied to determine whether there is a significant difference in the values of these variables for the group of farmers who regard a risk source or risk-management strategy as important and those who do not see it as important.

In the Vanderkloof Dam area producer prices and weather variability are regarded as the most important risk sources in respect of crop production. In the case of livestock production the cost of operational inputs was however indicated as the second most important source of risk. Limiting debt commitments is regarded as the most important method of reducing risk. Harvest insurance and maintaining of financial reserves was awarded the second and third places respectively. Diversification and maintaining a flexible farm business are also regarded as important. In the case of a relatively large number of risk sources and management strategies significant differences were found between the average magnitudes of the socioeconomic variables of the two groups of farmers who respectively regarded risk sources and management strategies as important and unimportant. This implies that farmers' perceptions of risk, as well as possibly risk itself, may depend on certain socioeconomic factors. The perceptions of irrigation farmers recorded during this research largely correspond with the results of previous research.

The results of the survey indicate that farmers regard several risk-management strategies as important for counteracting risk. These include such management actions as limiting of debt commitments, making use of harvest insurance and diversification. The correctness of such perceptions can only be determined by analyzing these management actions at farm level with due consideration of the risk factor. Taking into account the farmers' perceptions, it makes sense to formulate certain risk-management strategies on the basis of the above-mentioned results.

The representative farms already reflect diversification at enterprise level. Addition of livestock enterprises of differing sizes to the irrigation area is therefore a form of diversification already practised in the area. Although extension is not the same as diversification at enterprise level, an increase of the irrigation area from 60 to 120 ha is a further form of diversification encountered in the area. Each RF therefore indirectly represents a diversification option that may be pursued. Although it cannot be realized in the short term, it still remains a possible risk-management strategy. Alternative crop-rotation systems can however be regarded as short-term risk-management strategies. On the basis of previous research conducted in the area, seven crop-rotation systems, including wheat, maize, soybeans, cotton and lucerne, were formulated as possible strategies for reducing risk at farm level.

Farmers who regard limitation of fixed liabilities as the most important method of managing risk, may consider maintaining a specific debt:asset ratio as a suitable risk-management strategy. For the purpose of the research the three debt:asset ratios encountered in the area were accepted as the three debt-management strategies. It was therefore possible to determine the consequences of each for representative farms of various sizes.

A third risk-management strategy which farmers may consider following, is the use of insurance against hail damage. Evaluation of the strategy of insuring against such damage, as opposed to no insurance, however demands information regarding the incidence and extent of hail damage in the research area. Data on the historic incidence and extent of hail damage in respect of various crops in the area were collected.

The results of Chapter 2 supplement the first part of the research in that it deals with the risk component at farm level that was not included in the formulation of representative farms in Chapter 1. Firstly, the farmers' perceptions of the importance of risk sources and risk-management strategies were determined. Thus it became obvious that yield and production risks have to be taken into account in risk-simulation models. The choice of risk-management methods of farmers in the research area rendered it possible, given the representative farms, to formulate practical risk-management strategies.

Once the first two chapters of this part of the report had been completed, six representative farms were formulated. In view of the limitations of each farm and taking into account the farmers' perceptions of risk, possible risk-management strategies that might be followed in the running of these farms were suggested. The models developed during this research and presented in the next three chapters rendered an economic evaluation of these six farms and the recommended strategies possible. Risk is however only discussed in the second and third modules (Chapters 4 and 5).

DECISION-MAKING SUPPORT AT ENTERPRISE LEVEL: A SHORT-TERM DETERMINISTIC MODEL

For the purpose of this research farm management is divided into two levels. First of all the management process at enterprise level is discussed, whereafter it is extended to farm level. Although decisions at enterprise and whole farm level are made in an integrated manner, the first model was developed as a support system for decision making at enterprise level.

In the management process at enterprise level the most efficient enterprise or combination of enterprises must be chosen and then also managed efficiently. At enterprise level decision making does not only include direct income/cost aspects, but *inter alia* also the management of labour, the mechanization system and irrigation. The farmer often has various sources of data at his disposal, but the format in which the information is available limits its usefulness and the data therefore require further processing. Such processing is usually of an extensive and complicated nature and therefore instruments for this purpose are not available. Development of a decision support system (DSS) which can be used as a management aid can serve to address the above-mentioned needs.

The purpose of the third chapter is firstly to introduce and discuss a deterministic computer model for decision-making support at enterprise level. A further aim is to illustrate the application possibilities of this model by evaluating alternative risk-management strategies at enterprise level in a deterministic manner. This includes the six representative farms and seven crop-rotation systems.

The model was primarily developed with a view to the provision of reliable and relevant information on which decisions can be based. The model was developed by means of the Lotus 3.4 spreadsheet program to be as flexible as possible and able to handle four crop and two livestock enterprises. In addition to this, the system is user friendly and practice-oriented.

The input and output components of this first module are presented together with the data of the second representative farm that includes 60 ha under irrigation and 500 ha of grazing land supporting mutton sheep. On the part of the farm under irrigation a crop-rotation system involving wheat, maize, soybeans, cotton and lucerne is used. In addition to the above-mentioned implementation of Module 1 with the introduction of the model, the results of the evaluation of the representative farms and crop-rotation systems are compared in table form.

The input of the DSS at enterprise level is handled as general, crop-enterprise and livestock-enterprise inputs. The general input, dealt with on page A1, rendered it possible to group later transactions as unique according to the month in which they occurred and the category in which they fall, as well as according to whether they were credit or cash transactions. Economic parameters are supplied on page A2. Quantities for the calculation of mechanization costs, the enterprises concerned, as well as details regarding irrigation systems used are supplied on page A3. On the following two pages technical and economic details regarding each implement in the mechanization system are provided. On pages A6 and A7 the means of production of the crop and livestock enterprises are listed. Since it is handled centrally, it holds the advantage of facilitating the updating of prices. The products of the various enterprises and the prices obtained are listed on page A8 dealing with general input.

Four pages (B1 to B4) of input are provided for each crop enterprise. On the first two pages the products yielded by the enterprise and the means of production required are indicated. The month code and type of money flow is indicated in the case of each entry. Distinction is made between inputs which are production and area dependent. The irrigation system concerned and monthly irrigation quantities are also indicated. On the last two pages operational data are provided. Ten types of operations are possible in the case of each enterprise. The area concerned and the month in which each operation is supposed to have taken place are also indicated. In the case of each operation up to four sets of implements, each of which may consist of a tractor and two implements, may be involved. On the basis of the technical variables the program is able to calculate which part of the area is cultivated by each tractor. The operator of the program can effect changes in this regard, as well as in respect of diesel consumption. Input pertaining to livestock enterprises are, with the exception of two aspects, provided in the same way as crop-enterprise input. One difference is that the mechanization component falls away, and secondly that the labour hours required are indicated instead of irrigation quantities.

The power of this model is illustrated by the extent and nature of the program output. Twenty-three tables, numbered Table R1 to R23, contain different sets of information that can be used to support decision making.

Tables R1 to R9 of the model provide support in respect of management of mechanization and labour. The annual mechanization cost of each implement is indicated in Table R1 as a variable cost per hour, as well as the different categories of variable and fixed cost. An important advantage is that the variable cost can be calculated according to the actual number of hours that each implement is in operation, as determined by the crop areas and the extent to which the implement is utilized in each enterprise. Interest cost is calculated as an opportunity cost taking into account inflation and is also included in the enterprise budgets that follow later. Depreciation is calculated over the economic lifespan of each asset according to the straight-line method, but is adjusted to accommodate inflation so that the time value of money remains the same for all analyses. Fuel cost is calculated as a function of the tractor load, the engine size and the number of hours in operation. The variable nature of repair costs is taken into account by calculating it as a coefficient of the list price of 1 000 hours of work. By means of this table implements with a high fixed-cost component and low intensity of use can therefore be identified quite easily.

The monthly hours of use of each implement in each enterprise as well as in total are also indicated in Tables R2 to R6. The advantage is that mechanization planning can be done per crop as well as for the total system according to the actual hours that each implement is used. Labour management can be planned with the help of Table R7 that indicates labour hours required on a monthly basis. In the same way irrigation management can be improved by Tables R8 and R9 that indicate the monthly water applications and the number of pumping hours respectively. In the case of water quotas, each crop-rotation system can therefore be evaluated in terms of monthly water requirements.

The choice and management of enterprises are facilitated by the flow of funds that is indicated for all enterprises in Tables R10 to R15. The monthly flow of income and expenditure and the interest implications thereof are clear. This renders it possible to identify enterprises that can bring pressure to bear on cash flow. Enterprise budgets, which are an important aid to decision making, appear in Tables R16 to R21. These budgets extend from gross margin level to the level of income over specified cost. The full implications of specialized implements that can be used in one enterprise only are indicated in this way. In the case of enterprise budgets, the budget also reflects the income and cost for the total area.

The last two statements of output of this module are the credit and cash-flow statements. In the DSS the credit flow is introduced to handle the co-operative account in a practical manner. Management and planning of co-operative credit on a monthly basis can be facilitated by the credit-flow statement (Table R22). This includes aspects such as application for and control of the credit limit. The cash-flow statement, R23, reflects the course of the bank account before taking into account overhead costs and income. If income derived from crops clears the balance of the credit-flow statement in a specific month, the surplus is transferred to the bank account as cash flow. This distinction made between credit and cash flow in the DSS renders the model realistic and practically usable.

Practical application of the model to the six representative farms and seven crop-rotation systems resulted in Tables R1 to R23. These provide each decision maker with the opportunity to use the information that is of relevance to him. Only certain data are abstracted from these tables to compare the farms and crop-rotation systems.

In the case of the representative farms credit flow decreases to the extent that livestock enterprises are included, because the inputs of the livestock enterprises are bought on credit, while the income of these enterprises is received via the cash-flow statements. As far as cash flow is concerned, it is profitable to include livestock. Doubling the irrigation area also holds certain advantages. The most important advantage is that fixed mechanization cost per hectare decreases considerably.

The seven crop-rotation systems were compared with one another in terms of mechanization costs at enterprise level. The variable mechanization costs, as well as the required labour and mechanization hours of the two systems that do not include lucerne and of which the area utilization amounts to only 150 %, are clearly lower than those of the other systems. With regard to credit flow, two crop-rotation systems require credit limits higher than R45 000 and also generate the highest interest cost. All seven systems end with a surplus on the credit-flow statement in December, which is carried over to the cash-flow statement. Since lucerne is sold for cash, the cash-flow statement provides a comprehensive image of the crop-rotation systems and the two systems that do not include lucerne fall behind the others if the end balance of cash flow is taken as a yardstick.

Although the above-mentioned results only apply at enterprise level and do not take risk into account, important underlying aspects that are not indicated in the analyses at farm level come to the fore here.

The main result, which is presented in Chapter 3, is the application of Module 1 of the decision support system to the representative farm with 60 ha of irrigation land and a herd of sheep consisting of 160 ewes. The output of this model facilitates the management process at enterprise level by providing several tables with information regarding the planned enterprise combinations and management methods. On the basis of information contained in a few of these tables, a comparison at enterprise level is drawn between the representative farms formulated in Chapter 1 and the proposed crop-rotation systems.

The importance of risk, as indicated in Chapter 2, is however not taken into account in this deterministic model. If risk becomes important in the choice between options, as is indeed the case when it comes to a choice of risk-management strategies, Module 1 proves insufficient as a decision support system. Accordingly Module 1 is supplemented by Module 2 that renders it possible to take risk into account in the decision-making process at enterprise level. This module is presented and discussed in Chapter 4.

DECISION-MAKING SUPPORT IN RESPECT OF RISK MANAGEMENT AT FARM ENTERPRISE LEVEL: A SHORT-TERM STOCHASTIC MODEL

From a risk-management point of view, computer models that treat yields and prices as constant values have limited application potential. The gap between theory and practice can be bridged by developing instruments to provide relevant risk-management information in good time. The purpose of the fourth chapter of the report is to extend the model discussed in the previous division with a view to providing support for risk management at enterprise level. It comprises the development of procedures to define price and production risks, and to define risk in terms of trends concerning the most important decision-making variables at enterprise level, as well as the ability to take fluctuating interest rates and sources of risks such as hail into account. In addition to the above, alternative risk-management strategies at enterprise level are evaluated.

The separate development of the second module that is linked to Module 1, holds the advantage that static analyses at enterprise level are not burdened with the additional data of risk analyses, but also that risk analyses can be executed without the bother of once again having to provide all the data at enterprise level as input. In the model risky variables are treated as distributions and the output of the model can therefore also be presented as distributions. The simulation of risk and definition of variables as different distributions were rendered possible by using the @RISK program in addition to Lotus. Risk simulation was executed with 150 iterations that took 2 hours and 45 minutes on a 486 DX computer.

The analyses of the representative farms and crop-rotation systems that were executed statically in Chapter 3, can be done stochastically by means of Module 2. Sets of simulated yield levels are used in the application to take production risk into account. By making use of *inter alia* time-series analyses and subjective probabilities, cumulative probability distributions were compiled for the production price of each crop. On the basis of empirical data from the research area, distributions were compiled which reflect the probability and extent of hail damage to wheat, maize, soybeans and cotton. Hail damage was simulated in respect of three crop-rotation systems. The interest on a bank overdraft and the co-operative account are treated as variable in the model.

As in the case of Chapter 3, the stochastic model is the most important result presented in Chapter 4. Therefore the input and output components of Module 2 are discussed. Linking this second module to Module 1 holds the advantage that only the risk input needs to be provided.

On the first page the enterprise names and main products of each enterprise provided in the first module are indicated. The type of data input for the yield and price levels of each principal product, which can be provided as input in five different manners, has to be indicated. The second type of risk input required by the model is the correlation between risk variables. On the second page risk involved in the cost of credit is handled. Since there is an interconnection between interest rates, all the rates are treated as possible deviations from a fluctuating so-called index rate. The number of iterations that have to be performed during each simulation is also indicated on the second page.

The following 12 pages, on which the input for Module 2 is provided, display the same format. On these pages the user has to define the price and production risk of the four crop enterprises and the two livestock enterprises. Price or yield data are introduced as input in 5 different ways depending on the manner in which risk is reflected on the first input page. The first and most simple option, as in the case of Module 1, is constant values. A second option is to provide single values, for instance, as a series of historic or simulated yields with the assumption that each value has an equal chance of being realized. As a third input method the variable can be directly indicated as a cumulative probability distribution. The last two manners in which price and production risk can be defined are by providing the input as either a normal or a triangular distribution.

The final risk input concerning Module 2 concerns the question whether the yield of crops must be adjusted to accommodate hail damage or not. If indeed it must, the cumulative probability distributions of possible hail damage and the correlation between hail damage in the case of different crops must be provided.

The output of this decision support system includes eight tables and 16 figures. Since risk results in distribution of performance criteria, the distributions are represented graphically.

The first two tables, RR1 and RR2, are the credit- and cash-flow statements in which prices, yields and the cost of credit are treated as stochastic variables. As a direct result of this, each of these statements only reflects the situation as in one of the 150 iterations and should therefore preferably be regarded as a means towards the ultimate purpose of providing support for risk decision making.

Table RR3 reflects the yield and production risks of the product of each crop as a cumulative probability distribution. In Table RR4 the price of each enterprise is defined in similar fashion. Each distribution is also represented graphically and the descriptive statistics calculated for each. On the basis of these data each decision maker can make adjustments once he has studied the implications of his data input.

At enterprise level production and price risks are reflected in the course of credit and cash flow. Credit-flow risks that are not subject to further change due to overhead variables are indicated in Tables RR5 and RR6 and represented graphically in Figures 13 and 14. Because income inflows occur in May and December, the influence of risk is indicated by the range of the distributions. From Tables RR7 and RR8 it is clear that cash flow can differ drastically from one month to another. The possibility of an overdraft on the bank account is indicated for each separate month. The monthly cash-flow distributions are represented in Figures 15 and 16. Since risk is taken into account in these two statements, it becomes possible to manage cash and credit flow, since possible minimum values and the probability of an overdraft are known for each month.

With Module 2 available, the representative farms and crop-rotation systems, as well as the use of insurance against hail damage were evaluated. Since it was done at enterprise level, the analysis comprises the course of cash and credit flow.

The evaluation of the representative farms reveals that inclusion of livestock is risky from a credit-flow point of view. The advantages in terms of cash flow however outweigh the above-mentioned disadvantage. Doubling of the irrigation area results in realization of economic benefits. In the case of the larger farms, risk decreases at enterprise level because the minimum level of cash flow increases with an increase in size, although the relative variability remains constant.

The relative variability in money flow of the different crop-rotation systems does not display much variation. The higher minimum value of the end of the year balance of a crop-rotation system comprising 30 ha of wheat, 15 ha of soybeans and maize and 30 ha of lucerne is indicative of a risk-reducing advantage. The results support the farmers' argument in favour of more extensive area utilization in order to promote cash flow. The benefits attached to lucerne with regard to the promotion of cash flow are confirmed.

From the simulation of the influence of hail damage on three crop-rotation systems, it is clear that the choice of a crop-rotation system can reduce the advantages attached to insurance. If more vulnerable crops are introduced into a crop-rotation system, the risk of a negative cash flow increases considerably, but simultaneously also the average cash flow that can be expected.

This short-term stochastic simulation model that was developed fulfils the need for a practical, yet economically based aid that can raise the level of risk management at enterprise level. This flexible instrument is particularly capable of providing strong support for short-term decisions that have to be made relatively frequently at enterprise level.

The influence of decisions made at enterprise level extends to the performance of the business at farm level. Overhead variables also contribute to uncertainty in a business. The same need for decision-making support experienced at enterprise level therefore also exists at whole farm level - that is, if it is not even more essential at farm level. The final module of the total decision support system, which promotes and facilitates risk-related decision making at farm level, is presented in Chapter 5.

DECISION-MAKING SUPPORT AT WHOLE FARM LEVEL: A SHORT-TERM STOCHASTIC MODEL

Management decisions concerning new investments or the taking on of new commitments can only be evaluated by means of financial feasibility studies at farm level. Although models cannot simulate the complex decision-making situation of farmers completely, inclusion of investment, production and marketing decisions may provide insight into the interaction between these decisions, especially as far as risk is concerned.

The lack of instruments to simulate risk and decision making in respect of a farm business at whole farm level on a monthly basis, has resulted in this third module of the decision support system. The module further extends the system through the inclusion of overhead variables that are not included at enterprise level. Performance measures at farm level in which risk plays a role can be simulated. A further purpose of Chapter 5 is to model risk-management strategies at farm level.

Since farm enterprises form the core of a farm business and these data have already been provided in the first module, only overhead variables have to be provided as additional input in the case of Module 3. The price- and production-risk data are obtained through Module 2. This implies that only the risk involved in the cost of interest charged on medium- and long-term loans needs to be defined.

The final level at which the possible risk-management strategies can be evaluated, namely whole farm level, is rendered possible by Module 3. The influences at farm level of the representative farms, crop-rotation systems and hail insurance as methods of managing risk, are therefore determined in Chapter 5. In Chapter 2 we have seen that farmers regard limitation of fixed commitments as the most important management strategy for counteracting risk. The possibility of evaluating the risk implications of debt only materialized with the development of this third module. Consequently the effectiveness of maintaining specific debt:asset ratios as risk-management strategies is evaluated in Chapter 5. On the basis of the typical debt:asset ratios determined for the research area, ratios of 30, 50 and 70 % are analyzed as levels that may be maintained by a manager. The debt-management strategies are analyzed for two of the representative farms.

The input of the third module is presented on four pages. Overhead cash flow that has not already been taken into account at enterprise level, is provided on the first page. Asset values, including the market value of various soil types, are provided as input on the second page. The user of the model is provided with an opportunity to adjust the market values of the mechanization system and breeding stock if these values, calculated on the basis of the enterprise level, prove to be too high or too low. This may be the case if depreciation is overcalculated. Details regarding long- and short-term obligations are specified on the third input page. Provision is also made for new loans negotiated during the period under analysis. At the bottom of the third input page one has to indicate whether the production-credit account has to be discharged at the end of the period of analysis. From an evaluation point of view, only one yardstick for money flow would then apply, since the end balance of the credit-flow statement would be zero. The last input component is the specification of different levels for interest rates on medium- and long-term loans to be able to calculate risk on the basis thereof.

At whole farm level the performance of a business is judged on the basis of the cash-flow, income and balance statement where the course of distributions of the most important variables contained in these statements is provided as output. The cash-flow, income and balance statements are supplied in Tables RRR1 to RRR3. If risk is taken into account in the analyses (*i.e.*, if constant options are not used in Module 2), these three statements reflect the situation during one of the iterations. The value of the three statements then merely is that they serve to indicate which variables were taken into account in which manner. Since all cost of credit has been taken into account in this module, the cost of interest on each source is presented as distributions in Table RRR4 and presented graphically in Figure 17. The influence of fluctuations in the interest rate, as well as of variations in respect of the amounts on which the interest is calculated, are illustrated by the distributions. Cash-flow risk at farm level can be identified in Tables RRR5 and RRR6. The risk can be determined in terms of the fluctuations as well as on the basis of the probability that negative cash flow will be experienced. Management and advance planning of liquidity can therefore occur on a monthly basis. Profitability and solvability are presented as a relative as well as absolute performance measure in Table RRR7 and Figure 20 and 21. Farm profit and own capital are indicated as distributions.

The computer models (Module 1 to 3) were validated by verifying each equation in the computer program for different deterministic runs.

The evaluation of the alternative risk-management strategies at farm level in Chapter 5 renders it possible to make a global assessment of the influence of each strategy by not only taking cash flow into account, but also profitability and solvability.

The different representative farms represent farm situations in which diversification can be pursued. As opposed to the increase in net cash flow that can be effected by including the livestock enterprises at enterprise level, their inclusion has a negative impact on cash flow at farm level. This implies that the fixed obligations of a debt:asset ratio of 30 % on the livestock enterprises cannot be supported by the enterprises. Doubling of the area devoted to crop production, however, has a beneficial influence on the cash flow. These trends are indicated by profitability and solvability performance measures. From the point of view of risk, it is therefore a good idea to extend the area under irrigation from 60 to 120 ha, but inclusion of mutton-sheep enterprises will only prove beneficial if the debt:asset ratio pertaining to it comes to less than 30 %.

The two crop-rotation systems with 150 % area utilization and which do not include lucerne can prove unfeasible at farm level. These systems include wheat, maize and cotton, as well as wheat, soybean and cotton respectively. The crop-rotation system, comprising 30 ha of wheat, 30 ha of soybean and 30 ha of lucerne yields the highest minimum level of cash flow and farm profits, but two of the other systems outperform this system in respect of maximum value. Accordingly a risk-seeking decision maker will indeed prefer one of the other systems.

The risk element of crop-rotation systems that are already risky increases dramatically with the inclusion of hail damage. The annual premium that is saved can indeed lead to an increase in the average cash flow, which is a theoretical figure. The uncertainty of profitability is not increased as dramatically by the inclusion of hail damage as that of cash flow. The link between the type of crop-rotation system and the insurance decision is confirmed by the differences in the benefits of insurance in the case of different crop-rotation systems. In the final instance the preference of the decision maker will also determine his choice of option in this case.

Cash flow is very sensitive to an increase in debt. The largest representative farm's chance of realizing a positive cash flow is only 63 % if the debt:asset ratio is 50 %. Farm profit, however, remains positive, even in case of a 70 % ratio. With the exception of the liquidity problem, capital growth can still occur in case of a debt:asset ratio of 50 %, but not if it is 70 %. The risk advantage of maintaining a low debt:asset ratio exceeds that of the other options in respect of risk management. These results support farmers' viewpoint that limitation of fixed obligations is an important measure for counteracting risk.

Following the introduction of Module 3 in Chapter 5, the set of three modules can be seen in perspective. Although Module 1 will prove sufficient in certain decision-making situations and can also be implemented independently from the rest, Module 2 requires the output of Module 1. Similarly Module 3 is dependent on both the previous modules. With this complementary set of three short-term models, instruments have been created which ought to prove capable of eliminating the deficiencies, especially in respect of risk management. Implementation of the model of this research in Chapters 3, 4 and 5 however holds the disadvantage that each level of the evaluation appears fragmented in Chapters 3 to 5. It has however been done in this way because the emphasis of this research must fall on the models and not on the applications. The evaluation and discussion of the risk-management strategies of diversification, insurance and debt management could have been improved by evaluating each strategy on a continuous line with all three models.

Each management strategy is evaluated at the highest level in Chapter 5, namely in respect of liquidity, profitability and solvability. In spite of this an adviser or user of the program will not necessarily choose a single strategy in certain cases, because the risk preference of the decision maker is not known. Although the risk perceptions of farmers in the area were determined in Chapter 2, there is still uncertainty regarding their risk preferences. Chapter 6 deals with this aspect.

MEASUREMENT OF IRRIGATION FARMERS' ABSOLUTE RISK-AVERSION COEFFICIENTS BY MEANS OF THE INTERVAL METHOD

Efficiency criteria, which effect a balance between the expected outcome and the possible distribution of outcome, render it possible to identify risk-efficient alternatives. The criteria however, demand that the risk preferences of decision makers be defined in terms of their absolute risk-aversion coefficients. This information is not available concerning irrigation farmers in the RSA and assumptions in this respect cannot be made in an unqualified manner.

The goal in Chapter 6 is to measure the risk preferences of the farmers empirically and determine how consistent these preferences are. Once this information is available, it will be possible to determine which of the risk-management strategies in Chapter 5 can be regarded as risk efficient.

The interval method, which renders it possible to determine the lower and upper limits of the absolute risk-aversion function of a decision maker by requesting him to make a number of choices between carefully chosen cumulative probability distributions, has already been employed in various studies. The way in which the method is used has certain implications. The purpose of the measurement determines the number of intervals and the range of the intervals on the scale according to which the preferences of decision makers are determined. The use of six values in each distribution among which the decision maker can make a choice renders it not too difficult to make a choice, and the choice can be compared to the six sides of a dice. The disadvantage of risk measurements at various levels of income, relatively close together, is that the decision maker is required to judge the distributions at a level of which he has no practical experience. Distributions that extend over a very small interval, imply that the options among which a choice has to be made can be so theoretical in nature that in practice they will not fall within the cumulative distributions which the farmer experiences at all. Consistency of preferences should also be tested.

The risk preferences of farmers in the Vanderkloof Dam area were determined in two phases by means of personal interviews. During the first survey 64 farmers were visited and on the basis of these results 30 farmers were involved in a follow-up survey.

During the first phase a risk-measurement scale that had previously been used in American studies was adapted for use under South African conditions. By means of the INTID program distributions with six values each were generated at bank-balance levels of 0 to R180 000 with intervals of R30 000. The difference between the minimum and maximum possible values was taken as 25 % below and above the particular bank-balance level. The bank-balance level was chosen as a performance measure because the farmers were able to identify with it. A questionnaire was compiled by making use of the distribution pairs that divided the absolute risk-aversion range of the decision maker. On the basis of each choice, a choice had to be made between the following set of distributions and thus the absolute risk-aversion range was halved each time. Although seven questions were involved, only three could be chosen. Once this had been done, the decision maker was classified under one of the eight risk-aversion categories which ranged from risk seeking to risk aversive. To test for consistency the same *modus operandi* was followed in the case of the other pairs of distributions.

As a result of deviation between the local results and those of other studies, a follow-up survey was undertaken. Because the farmers' preferences fell within the extreme categories, the original risk-aversion scale that extended over a wider range of absolute risk aversion was also used. For both scales distributions with minimum values that once again fell 25 % to both sides of the bank-balance levels, but which also included a variation of only 5 % above and below the levels concerned, were generated. This second phase therefore included four sets of questionnaires compiled in such a manner that the last questions of one questionnaire automatically led the decision maker to the first question of the next questionnaire.

After the farmers' attitudes had been measured empirically, the model rendered it possible to determine which risk-management strategies the farmers would prefer with the help of generalized stochastic dominance (GSD). GSD was therefore applied to the distributions of farm profit and cash flow obtained in Chapter 5. In this way the farmers' preferences with regard to the representative farms, crop-rotation systems and use of hail-damage insurance were determined.

Before the results could be interpreted, the consistency of the farmers' preferences had to be determined. Thirty-nine of the farmers involved in Phase I completed the questionnaire in a consistent manner, a result that was significantly higher than would have been the case if random choices had been made. Farmers with questionnaires at the higher bank-balance levels were also significantly more consistent than those who completed questionnaires involving lower levels. The fact that a learning process could not be involved, since each farmer received only one questionnaire, serves to indicate that outcomes that extend over a wider range can be more easily weighed against one another in a consistent manner. Farmers in the area could be divided into two extreme categories, namely 17 as strongly risk seeking and 15 as strongly risk aversive. These results differed from the previous ones. Apart from adjustment of the measurement scale and the variation range of the distributions, the nature of the group of decision makers involved could have been a third contributory cause.

During the second phase of the measurement process the first two of the above-mentioned reasons were investigated. The great majority of the producers however still fell in the extreme categories. It would seem that increasing the variations in the distributions resulted in decision makers becoming more risk aversive. Adjustments of the scale, however, did not have as great an influence. In spite of scale adjustments and a change in the variation range of the distributions in the questionnaire, farmers in the research area still displayed reasonably extreme risk preferences. This might also have been the result of the theoretical nature of the measurement procedure.

If farm profit is taken as the performance measure according to which the farmers make choices, all the farmers in the area were found to prefer the representative farm business involving 120 ha of irrigation and 2 500 ha of grazing land. If cash flow is chosen as the performance measure, the 17 risk-seeking farmers in the area were found to prefer 120 ha of irrigation with a livestock enterprise comprising 160 ewes on 500 ha of grazing. Risk-aversive decision makers would prefer 120 ha under irrigation only. The risk involved in the extra fixed obligations resulting from the addition of the livestock enterprise, therefore was not acceptable to risk-averse farmers.

The choice of a risk-efficient crop-rotation system was more simple, since the farm profit and cash-flow distributions rendered the same results with GSD. The system involving wheat, maize and lucerne and yielding the highest profit and cash flow was preferred by risk-seeking to risk-neutral decision makers. Risk-neutral to risk-averse farmers were willing to forego the higher profit in favour of a higher minimum value in respect of profit and cash flow and therefore preferred the less risky system involving wheat, soybeans and lucerne.

Only farmers in the two most risky risk categories preferred not to take out insurance on a crop-rotation system that included wheat, soybeans and lucerne. These results are in accordance with the expectation that insurance lowers risk.

The results in Chapter 6 establish a link between the last aspect of risk treated in the research and the rest. The empirical measurement of the risk attitudes and the development of the decision support system made it possible to identify practical and efficient risk-management strategies for farmers in the research area.

CONCLUSION

In respect of this research distinction can be made between a development aspect and the empirical application of the research. These aspects however are integrated in Chapters 1 to 5.

The development aspect comprises the creation of the decision support system's three modules that are discussed in Chapters 3 to 5. This system is the principal result and has been designed to overcome a lack of aids that can be used to support risk management at farm level in a practical manner and in good time. It is a comprehensive but flexible system that can be employed in a wide range of farming situations. Although it has been developed as an aid for implementation at farm level, it can also make a major contribution from an advisory service and research point of view.

Chapters 1 to 5 all to a lesser or greater degree touch upon the implementation aspect of the research. In Chapter 1 representative farms were formulated which formed the basis of the subsequent analyses. The information obtained by way of establishing the risk perceptions of the farmers in Chapter 2 determined the method of risk simulation and, in addition, risk-management strategies were formulated on the basis of the data obtained and subsequently analyzed. In Chapters 3 to 5 the various risk-management strategies were analyzed by means of the developed models in order to illustrate the potential of the models, but also with a view to obtaining relevant results for the research area. In Chapter 6 the decision makers were included in the process in order to measure their preferences with a view to identifying risk-efficient management strategies.

From a risk-management point of view, maintaining different levels of fixed obligations has the most important consequences, especially in respect of cash flow. Only a debt:asset ratio of 30 % can be regarded as safe. Doubling of the irrigation area from 60 to 120 ha also offers a cash-flow advantage to farmers. Inclusion of a mutton-sheep enterprise depends on the particular farmer's risk preference. Risk-seeking farmers will indeed include livestock. Since a debt:asset ratio of 30 % renders the livestock enterprise risky, risk-averse farmers prefer to concentrate on irrigation only. Crop-rotation systems involving an area utilization of more than 175 % do not differ much in respect of risk. The choice between these systems also depends on the particular farmer's risk preference. The preferred crop-rotation system will include wheat and lucerne, or either lucerne or maize. The farmers' choice in respect of hail insurance is influenced by the particular crop-rotation system chosen. Although no insurance increases the total risk at farm level, risk-seeking farmers in the area prefer not take out hail insurance. These results of the application of the research, with due consideration of the input and assumptions on which they are based, can be employed as guidelines in the irrigation area below the Vanderkloof Dam.

IMPLICATIONS FOR FURTHER RESEARCH

Research that has been done necessarily serves to indicate further research possibilities. This is so because areas that have not received sufficient attention can be identified and because some aspects extend over a wider area than can be covered by a single study. Results obtained also provide opportunities for further research. Thus the current research has also opened up areas for further research that include the following:

i) The decision support system that has been developed naturally has unlimited application possibilities. This range from problems at enterprise level, such as the choice of mechanization systems, cultivation methods, labour requirements and the choice of farming enterprises, to problems at farm level, such as the choice of methods of financing, the influence of overhead variables and the consequences of purchasing or renting land.

ii) The inclusion of risk in analyses at farm level has rendered a whole field of research more accessible. Determination and analysis of the influence of subjective probabilities as a strategy for quantifying risk have now become possible. Probability distributions for the most important variables have to be determined. The influence and levels of correlation between chance variables can be investigated. The real influence of production and price risks at farm level can be simulated and, in doing so, it would become possible to identify and analyze risk-management strategies.

iii) Six representative farms for the research area that lend themselves to further research have been identified. The illustrated procedure can also be employed as a guideline. Further risk-management strategies for the particular research area can be evaluated. The debt:asset ratio that will indeed justify the inclusion of a livestock enterprise from a cash-flow perspective should be identified.

iv) The risk perceptions and risk preferences of a relatively homogeneous group of irrigation farmers have been determined. By conducting the same type of research in other areas and with other groups of farmers, it should be possible to determine the general applicability of the results of the current research. Risk-preference measurement requires further research to confirm the reliability of the hypothetical choices. A suitable *modus operandi* might be to verify the farmers' choices by means of the empirical distributions of the risk-management strategies that have resulted from the research.

v) The application potential of this decision support system justifies further development of the system. As a first step towards rendering general use of the system possible, all three modules should be programmed in a computer language. This would serve to obviate dependence on a spreadsheet program. A second step would be to use this system as a basis and extend it further as a model that can serve to support decision making with due consideration of risk, also in the long term. Practical implementation of the program should, as in the case of all computer programs, serve to indicate possibilities for improvement.

Two final suggestions can be made. Firstly, risk management as an integral part of farm management must be promoted by encouraging farm managers to regard economic variables as distributions that can be managed. Secondly, the utility of a decision support system is determined by the relevance and value of the information it provides, as well as by its user-friendliness. If the expected value of the information exceeds the cost and trouble involved in obtaining it, such a system will contribute towards improved decision making. Since the system that has been developed is capable of providing valuable information for decision-making purposes, it should be employed to improve risk management.