OPTIMAL ALLOCATION OF WATER RESOURCE IN IRRIGATED FARMING AT THE RAMAH CANAL VANDERKLOOF DAM

by

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I declare that this dissertation hereby submitted by me for the M.Sc. degree at the University of the Free State is my own independent work conducted under the guidance and supervision of a steering committee and a study leader and has not been previously submitted at any other university or faculty. Copyright of this study lies jointly with the Water Research Commission who funded this work and the University of the Free State.

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JACINTA MAMALEKE MAHLAHA

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LIST OF ABBREVIATIONS

C:	COTTON
CWD:	COMPLETE PARTIAL CROP WATER DEMAND
DWAF:	DEPARTMENT OF WATER AFFAIRS AND FORESTRY
F:	FARM
G:	GROUNDNUTS
GM:	GROSS MARGIN
HA:	HECTARE
IRR:	IRRIGATION WATER
L:	LUCERNE
LP:	LINEAR PROGRAMMING
M BENCHMARK:	MAIZE BENCHMARK
M:	MAIZE
MC:	MAIZE, COTTON
MCP:	MAIZE, COTTON, POTATOES
MG:	MAIZE, GROUNDNUTS
ML:	MAIZE, LUCERNE
MLC:	MAIZE, LUCERNE, COTTON
MLG:	MAIZE, LUCERNE, GROUNDNUTS
MLP:	MAIZE, LUCERNE, POTATOES
MVP:	MARGINAL VALUE PRODUCT
P:	POTATOES
TVP:	TOTAL VALUE PRODUCT FUNCTION
W BENCHMARK:	WHEAT BENCHMARK
W:	WHEAT
YR:	YEAR

ABSTRACT

The floodplain in the Orange River at Vanderkloof Dam is classified as semi-arid. Natural rainfall in the area is very low and cannot support crop production. Therefore, the feasible way of producing crops is through irrigation. Agriculture must be prepared to respond to limited water by becoming efficient in water use. Increase in efficiency requires that the demand and supply management by individual water users be optimised and the value of water derived as measures to achieve efficiency in water use.

The first part of the study involved a survey conducted at the Ramah Canal to ascertain the current farming situation and to determine whether economies of size existed in the area. Irrigated farms in the area were classified based on irrigation water rights into three average farm sizes of 75, 180 and 240 ha. Income and balance sheet statements were compiled to determine the financial situation of the three farm groups. From the statements, different financial ratios including solvency, liquidity, profitability and efficiency were calculated. The financial analysis showed that 180 ha farm group had the best solvency, liquidity, profitability and efficiency ratios. In the second position was 240 ha farm group. The analysis indicated that economies of size exists between farm groups with 180 ha farm being the optimal farm size to operate and 75 ha being the least efficient farm group.

In the second part of the study, optimal cropping mixes at the Ramah Canal were determined under constrained and unconstrained irrigation water supply. Five crop mixes were formulated for each farm group. Crops under investigation were maize, wheat, lucerne, groundnuts, cotton and potatoes. A Linear Programming (LP) model was developed to determine optimal cropping mix that gives maximum returns under unconstrained water supply (100 percent). The objective function of the model was to maximise total gross margin subject to the following constraints: total available water and land during summer and winter seasons, maximum area under each crop, labour and tractor power required by the crop mixes.

From the LP results, the total value product (TVP) functions presented as linear segments showing gross margin as a function of water applied were developed for each crop mix. The TVP functions indicated the sequence by which crops would be irrigated based on their contribution in maximising gross margin. Results showed that in summer season, potatoes would be irrigated first because of high profitability relative to other crops. As irrigation water becomes abundant, groundnuts, cotton, lucerne and maize will be irrigated in that order. Wheat was the only winter crop dealt with. From the TVP functions, Marginal Value Product (MVP) for water was derived. The MVPs were R0.09, R0.18, R0.25, R0.38, R0.39 and R3.64 for maize, lucerne, cotton, groundnuts, wheat and potatoes, respectively.

Sensitivity analysis was carried out by reducing the full water application level to 75, 50 and 25 per cent water availability to determine the response of different crop mixes under restricted irrigation water supply. Results showed that in summer season, maize is the first to be affected by water limitations. Next is lucerne, then cotton, and groundnuts. Potatoes are the last to be affected by water restrictions. Furthermore, under severe water restrictions, farmers could lose more than half of their potential income.

Water management strategies which farmers would follow in future when irrigation water is limited were determined. Farmers in 75 and 180 ha groups indicated that they would completely change crop mix under severe water restrictions. Farmers in the 240 ha group with lots of farm investments, are very sensitive to reductions in water supply and are prepared to quit farming if water limitation persists.

In conclusion, the study provided information and guidelines for choosing the best cropping strategies based on available irrigation water and other production resources. It is recommended that the study be done for a reasonable period of time since production is a continuous process. Furthermore, the potential of the area in producing high value crops should be investigated.

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION AND PROBLEM STATEMENT

Scarcity of water resources and increasing competition for water among users are very important social issues in water allocation. Due to rapid population and economic growth, demand for water by different sectors including agriculture has increased significantly (Rosegrant et al, 2000).

Water is one of the most important factors limiting agricultural development in South Africa. The average annual rainfall of the country is 451 mm, ranging from less than 10 mm/yr in the western deserts to 1 200 mm/yr in the eastern part of the country. Twenty one per cent of the country receives less than 200 mm/yr of rainfall hence the country is considered arid. The 44 per cent that receives between 200 mm and 500 mm/yr and is classified as semi-arid. This implies that 65 per cent of the country does not receive sufficient rainfall and it can be concluded that South Africa has insufficient irrigation water (FAO, 1995).

The major limiting factor for crop production that faces farmers on the Ramah Canal at Vanderkloof Dam in the Orange River catchment is potential scarcity of irrigation water. The mean annual precipitation of the area is approximately 400 mm compared to the world average of 860 mm (DWAF, 1997). By world standards, the Orange River catchment, including Ramah Canal area, can be classified as arid. Therefore, the only feasible way of crop production in the area is through irrigation.

According to DWAF (1997), irrigated agriculture is the main water user in the Orange River area and accounts for 54 per cent of the water from Vanderkloof and Gariep Dams. A small portion of water, about two per cent, is used for urban and industrial purposes. The rest of the water is lost through river losses (32 per cent), consumptive canal losses

(2 per cent) and environmental demands (10 per cent). Irrigation water is rationed among farmers according to the amount of irrigation water rights, which each farmer holds.

Although agriculture is the main consumer of water, it is the smallest contributor to gross domestic product (GDP) among major sectors of the economy as indicated in Table 1.1. In 1980, the agriculture sector contributed 6.2 per cent to the GDP. The contribution dropped drastically in the subsequent years to 4.6 per cent in 1990, 3.4 per cent in 1999 and finally to 3.2 percent in 2000.

Table 1.1: Percentage contribution to Gross Domestic Product by different sectors of the economy in South Africa

Sectors	1980	1990	1999	2000
Agriculture	6.2	4.6	3.4	3.2
Industry	48.2	40.1	30.8	30.9
Manufacturing	21.6	23.6	18.8	18.8
Services	45.6	55.3	65.8	65.9

(Source: South Africa at a glance, 2001)

The average annual growth of the agricultural sector as shown in Table 1.2 fluctuates from year to year.

Table 1.2: Average annual growth for different sectors in South Africa

Sector	1980-90 (%)	1990-00 (%)	1999 (%)	2000 (%)
Agriculture	2.9	0.6	3.4	2.5
Industry	0.7	1.0	-0.4	2.3
Manufacturing	1.1	1.2	-0.2	3.6
Services	2.4	2.6	3.3	3.6

(Source: South Africa at a glance, 2001)

In Table 1.2, the agricultural sector experienced the highest annual growth of 2.9 per cent from 1980 to 1990 compared to other sectors. This annual growth dropped to 0.6 per cent for the period 1990 to 2000, which made the agricultural sector the least growth sector in South Africa. In 1999, the agricultural sector had the highest annual growth (3.4 per cent) again, but this dropped to 2.5 per cent a year later. Even though the agricultural sector is not performing well compared to other sectors, this does not mean that the sector should be deprived of water.

In the past, developing new sources such as dams has satisfied the increasing demand for water in most parts of the world, including South Africa. Since this operation is costly and is unable to sustain agriculture and other water needs in the long run, the emphasis is now on improving the performance of existing water resource systems through efficient water demand and water supply management. Demand side management ensures equitable distribution of the available water and sustainable use of existing water resources rather than developing new ones (Mainuddin, Das Gupta & Onta, 1997; DWAF, 1998; Veitch, 1999).

In addition to the scarcity of irrigation water in the study area, high input costs and low output prices are exerting a price cost squeeze on farmers. The main crops produced in the area namely maize and wheat are regarded as low-value crops. In an attempt to maximise returns to the scarce water resource, a few farmers have started to produce high-value perennial crops such as pecanuts and vineyards. Therefore, the use of irrigation water does not appear to be economically viable unless it is used to produce high-value crops.

The other major limiting factor in the study area is the fact that the value of irrigation water is not known (Anon, 1998). The value attached to irrigation water is so small that it does not reflect its scarcity. Thus, water resources are readily transferred from irrigation to other uses such as hydroelectricity, municipal and industrial purposes (Bakker, Meinzen-Dick & Konrasen, 1999). Fair and efficient pricing of water is required to reflect its value as a scarce resource so that it is neither wasted nor mismanaged (Jad, 1999).

Inasmuch as water is a vital resource in agriculture, where it plays a major role in irrigating crops, its use must be optimised (Tsarikis, 1982). Optimal water allocation that will balance marginal gains with marginal costs is required for efficient irrigation water allocation among users, which will optimise cropping patterns and maximise returns (Bernado, 1985). Water management based on productivity parameters can improve irrigation water use by quantifying the profitability of irrigation water and treating water as an economic good (Reca et al, 2001).

One of the key decisions in irrigated agriculture is that of determining how much water should be allocated to different cropping areas. The decision-making analysis in irrigated agriculture can be conducted by means of models (Mainuddin et al., 1997; Tarjuelo, De Juan, Valiente & Garcia, 1996). Mathematical models based on linear programming (LP) techniques have been used extensively for water allocation problems and to maximise cropping patterns (Loucks, Stedinger & Haith, 1981). The LP model can be employed to maximise net returns, which is the main objective of commercial farmers practising irrigation, subject to agronomic restrictions. In addition, an LP model permits evaluation of any crop rotation. According to Ozsabuncuoglu (1977), through sensitivity analyses, consequences brought about by modifications such as price of inputs or water availability on farms can be studied. With the help of LP models, farmers can gain knowledge on how to change crop production practices and enterprise compositions for effective water management. This helps in establishing water allocation policies that suit management options, economists and farmers (Anon, 1998).

1.2 STUDY AREA

1.2.1 Orange River Basin

The Orange River basin is the largest river basin in South Africa, with a total catchment area of 1 million km^2, of which almost 600 000 km^2 is inside South Africa (DWAF, 1997). The general orientation map of the Orange River Basin is shown in Figure 1.1. The Orange River Catchment is subdivided into lower, middle, and upper catchments as shown in Figure 1.2. The study is conducted at the Ramah Branch Canal (Figure 1.3), which is in the Middle of the Orange River catchment.

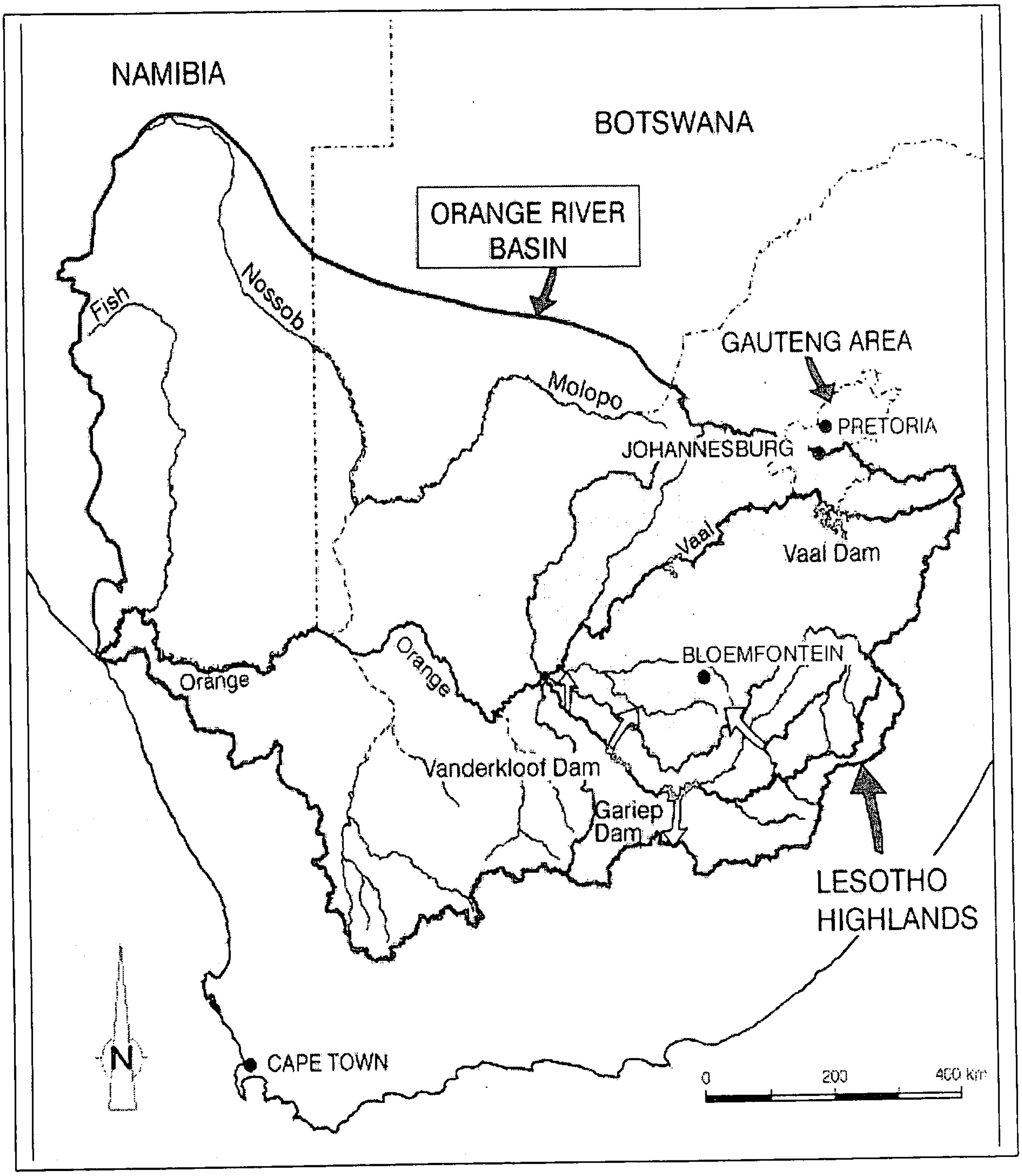

Figure 1.1: General location map of the Orange River Basin

(Source: WRP, 2001)

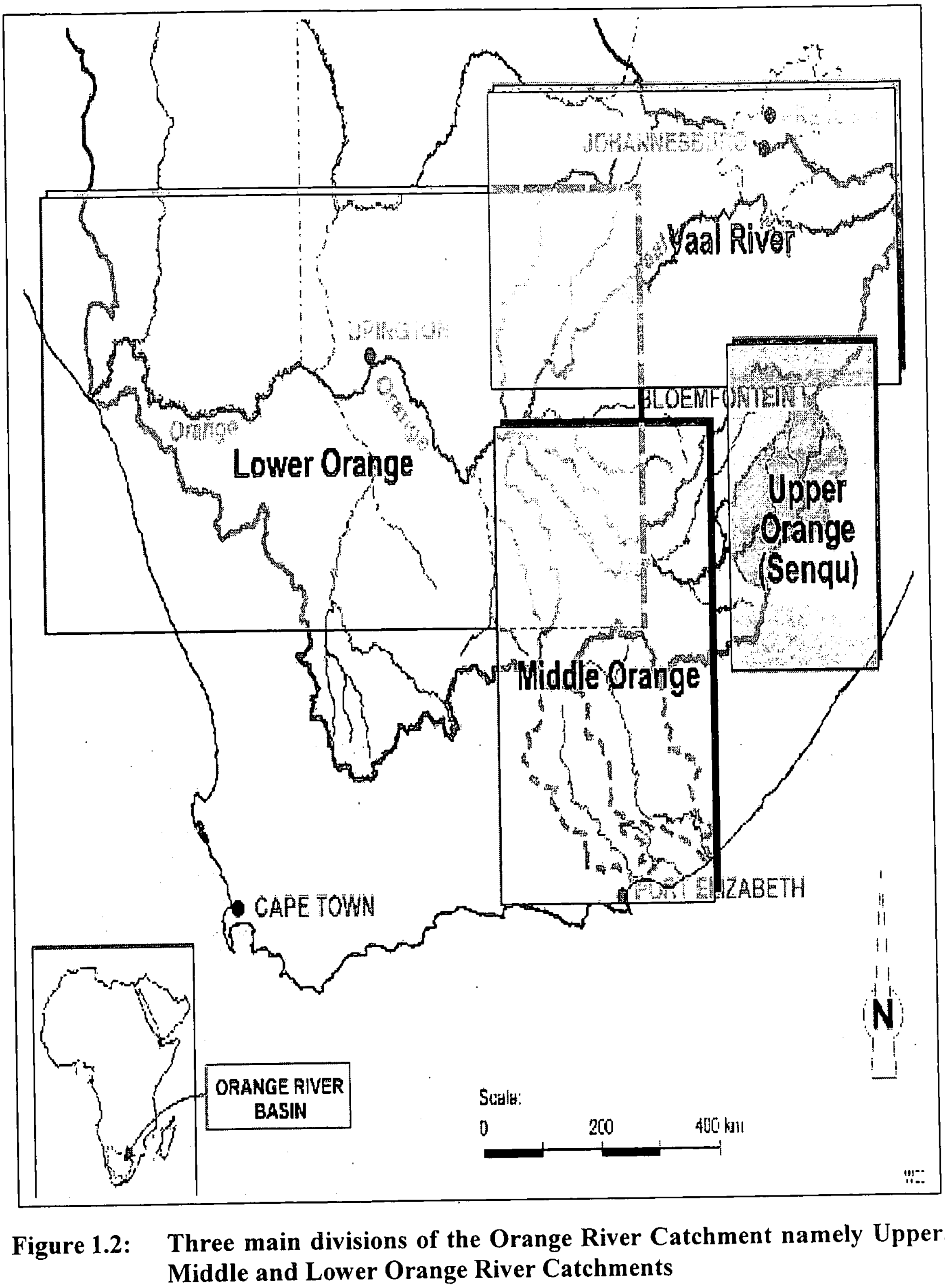

Figure 1.2: **Three main divisions of the Orange River Catchment namely Upper, Middle and Lower Orange River Catchments**

(Source: WRP, 2001)

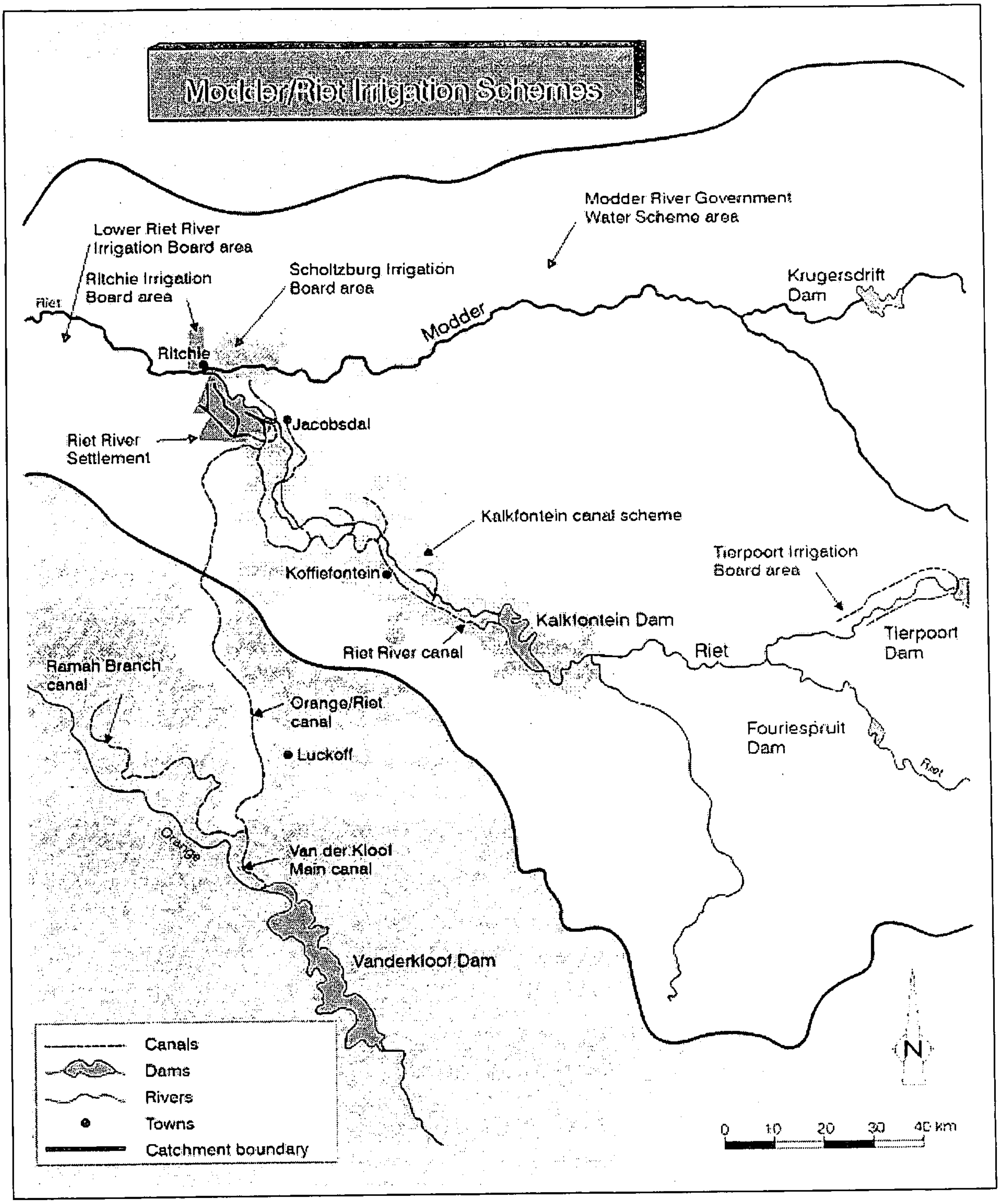

Figure: 1.3 The Middle Orange River Catchment showing Ramah Branch Canal

(Source: WRP, 2001)

1.2.2 Climatic conditions

The climate is characterised by hot summers and cool winters with sparse summer rainfall. Crop farming in this area is not feasible without irrigation. Water is highly limiting for crop production since Ramah Canal is located in a semi-arid region. Crop farming without irrigation is not feasible in the area. The major source of irrigation water is Vanderkloof Dam, the second largest dam in South Africa. The water is conveyed through Ramah Canal at the rate of 90 l/sec. The whole irrigated surface in the area is about 21 750 ha. The soils in the area comprise sandy loam, sandy clay loam and clay soil. In some parts, clay soil is the dominant soil.

1.2.3 Crops grown

Maize and wheat are the dominant crops in the area. Maize is grown in summer and is rotated with wheat, which is grown in winter and harvested early in summer. Other crops produced include lucerne, potatoes, cotton, soyabeans, groundnuts, beans, peas, vegetables, onions, vineyards and pecanuts. The respective areas of the crops are indicated in Table 3.1. Each farm is allocated 11 000 m^3/ha of area with irrigation water rights.

1.3 OBJECTIVE OF THE STUDY

This research aims to identify optimal irrigation water allocation strategies that farmers can use during winter and summer seasons, to adjust to limited water supply in the Ramah Canal and to maximise gross income subject to a given set of input constraints. Specifically, the following objectives are as follows:

1. To classify farms into different water-use groups and to describe the groups according to irrigation water rights.

2. To determine whether economies of size exists in crop production.

3. To construct a Linear Programming model for different groups of farms to determine the impact of different water allocation regimes on farm decision making.
4. To derive optimal cropping mix to maximise farm net returns subject to different water resource allocation and use scenarios.
5. To determine the marginal value product (MVP) of irrigation water as a proxy for water price in the study area.
6. To determine water management strategies that farmers would employ when subjected to different irrigation water reduction levels in the short, medium and long terms.

1.4 ORGANISATION OF THE STUDY

This thesis is structured into six parts. The study is introduced in Chapter 1, which covers the problem statement and motivation, description of the study area, main objective and specific objectives. Chapter 2 presents and discusses the theoretical and methodological framework related to the research objectives of the Ramah Canal. The research procedure is also discussed in Chapter 2. Chapter 3 presents the financial results of farms as well as development of representative farm groups based on irrigation water rights. In Chapter 4 the LP model is described while Chapter 5 reports the empirical results of the LP model in terms of optimal cropping pattern and resource utilisation at farm levels. Finally, Chapter 6 provides the summary, conclusions and recommendations from the analysis.

CHAPTER 2

THEORETICAL AND METHODOLOGICAL FRAMEWORK

2.1 INTRODUCTION

The aim of this chapter is to review the theoretical and methodological framework for optimising the allocation of irrigation water. The theoretical framework is first introduced by defining the terminology and concepts, thereafter the methodological framework and research procedure are discussed.

2.2 DEFINITIONS AND CONCEPTS

The following concepts are commonly used to address problems related to optimising allocation of water resources.

2.2.1 Water scarcity

Tisdell (1972) defines water scarcity as a situation whereby the quantity of water required by farmers for producing output exceeds available quantity of inputs. According to Schilling and Mantoglou (2002), water scarcity can be defined either as absolute or relative with respect to its severity. When water is absolutely scarce, it limits the survival and or development of an individual, a population, a society or an ecosystem. If it is relatively scarce, its limiting character can be overcome with technical, economical or institutional measures, usually at higher costs. Absolute scarcity of water is very rare and most situations involve relative scarcity of various degrees of severity (Schilling and Mantoglou, 2002).

2.2.2 Crop water production function

The effects of irrigation water on crop production are usually quantified by using crop water production functions, which describe the relationship of crop yield response to varying levels of water as an input. The relationship can be expressed as follows:

$Y = f(X)$

where:

Y is output

X is irrigation water

2.2.3 Economic efficiency

Economic efficiency is a criterion used to allocate a resource such as water optimally in a closed river basin or a dam (Tiwari & Dinar, 2001). It is measured in terms of crop output per unit of water applied and expressed as percentage of a desired or attainable productivity that is actually achieved. Efficiency is based on profit maximisation theory, whereby maximum profit is realised when the marginal cost is equal to the marginal revenue. For efficient crop production enterprises, inputs must be optimally allocated between crop enterprises. If inputs are used efficiently, the output of one crop enterprise can only be increased by decreasing that of others, that is, by shifting resources from one enterprise to another.

2.2.4 Marginal cost

According to Deardorff (2000, 2001) marginal cost is the increase in cost that accompanies a unit increase in output; the partial derivative of the cost function with respect to output.

2.2.5 Marginal product

In a production function, the marginal product of a factor is the increase in output due to a unit increase in the input of the factor; that is, the partial derivative of the production function with respect to the factor. In a competitive equilibrium, the equilibrium price of any factor is its marginal value product in every sector where it is employed (Deardorff, 2000, 2001).

2.2.6 Marginal value product (MVP)

Marginal value product is defined as the market value of the output generated by the employment of one additional unit of a factor of production. It is equal to the marginal product of a factor multiplied by the unit selling price of the extra output produced. (Bannock, Baxter & Evan Davis, 1998). Marginal value product can therefore be referred to as the amount a farmer can afford to pay for additional unit of an input.

2.2.7 MVP of water

The MVP of water is defined as the value of one additional unit of water used in a production process or the price a rational water user can afford to pay for one additional unit of water

2.2.8 Optimisation

Optimisation involves finding a strategy that maximises or minimises a given objective function, such as maximising profit subject to limitations like those imposed by the available resources. It is regarded as central to economics theory, as it involves rationalising scarce resources. In optimising scarce resource use, the study of economics requires that mathematical theory be applied. As a result, the problem of economic optimisation involves the use of mathematical programming techniques in order to maximise an objective function subject to limitations imposed by available resources. In economic theory, linear functions are frequently used where farmers' profit can be expressed as a linear function of its output and resources used (Tisdell, 1972).

2.2.9 Water quota

Water quota is a specified water quantity entitlement allocated to irrigation farmers who possess water rights. The water quota is implemented in terms of allocation of water share in fixed amounts to different irrigation farmers sharing water from the same water source (Tiwari, & Dinar, 2001).

2.2.10 Water rights

Tiwari and Dinar (2001) define water rights as rights acquired by irrigation farmers for the abstraction, diversion and use of irrigation water. Water rights are acquired through quota, under the common property regime, and provide ownership of water to farmers. Water rights specify how water is to be divided between farmers. Therefore, for efficient allocation of irrigation water, clear allocation of water rights is a prerequisite. According to Dudley (2002), the water rights should be non-attenuated, explicit, exclusive and explainable

2.2.11 Gross margin

Gross margin of an enterprise is the value of the enterprise gross production less directly allocatable variable costs.

2.2.12 Gross farm income

This is the sum of the gross income from all the cash crops enterprises on the farm plus sundry farm incomes.

2.2.13 Total farm costs

Includes the total costs of all resources used in the farming enterprise during a particular year. Total costs consist of fixed and variable costs.

2.2.14 Net farm income

Net farm income is defined as the return related to land, capital and management. Net farm income is calculated as gross farm income less total farm costs.

2.2.15 External factor costs

These costs comprise interest, rent, wages and salaries and management salaries actually paid in respect of hired production factors.

2.2.16 Farm profit/loss

This can be defined as the remuneration to own land, capital and management (including own and unpaid family labour) and can be calculated as net farm income less payment for hired land and management payment for borrowed capital.

2.2.17 Non farm income

This is income obtained from sources other than the farm.

2.2.18 Household expenses

This is what the farmer spends on family matters other than on farm business.

2.2.19 Farmers profit or loss

This is the balance, which may per chance result if all production factors are fairly remunerated at a predetermined rate.

2.2.20 Economies of size

Redman (1981) defines economies of size as a certain size of farm or certain range of size that is more efficient to operate than either larger or smaller farms. According to Van Zyl, Binswanger and Thirstle (1995), economies of size is important when examining the relationship between farm size and productivity. The highest output per unit area is often achieved not by the smallest farm size category but by the second smallest farm size class, suggesting that it is most efficient to operate on medium farm size. The farm size can be measured by number of hectares, crop output, gross farm income, amount of capital, and labour employed.

2.2.21 Parametric programming

Parametric linear programming is a technique that allows a series of optimum plans to be produced for differing levels of any parameter of the problem. Such parameters may be any of those that comprise the activity gross margin (product price, price of flow inputs or yields) or the requirement per unit of any activity for any supply input (Rae, 1994).

Nwonwu (1983) further defines parametric programming as follows:

> *"Parametric programming is a post optimality procedure used to investigate the effect on the optimal solution of a systematic change in costs or resource coefficients in an optimisation model. The process involves the replacement of a chosen coefficient or vector with new one which is the sum of the replaced value and a multiple of the corresponding value of a change vector."*

2.2.22 Total value product (TVP) function

Total value product function can be expressed price times output (P.TPP) expressed as a function of an input used.

2.3 THEORETICAL FRAMEWORK FOR OPTIMISING IRRIGATION WATER RESOURCE USE

Although water may seem relatively abundant from a global perspective, in some geographical locations water is quite scarce and needs to be efficiently managed (Tiwari & Dinar, 2001). Water management involves several related issues that include water storage, allocation and production of various crops. Water allocation is an economic problem of deciding how the total available water should be allocated among potential users including the irrigation sector. To solve the problem of water allocation for the irrigation sector, water use for different crop combinations must be optimised and economic efficiency for each combination obtained. According to economic theory, an economically optimal allocation of irrigation water can be based on the crop water production function, which is used to optimise farm level irrigation by means of economic maximising techniques or mathematical programming techniques.

2.3.1 Crop water production function in optimising water allocation

Crop water production functions are very important in determining or specifying the use of water resources and pattern of output, which maximises farmers' profit (Heady & Dillon, 1964). According to English (1990), an irrigation system is considered optimal in economic terms if it maximises gross profit subject to constraints imposed on the system. Since gross income is equal to crop yield multiplied by crop price, the relationship between irrigation water use and gross income has the same general graphical shape as the applied water curve. Crop water production functions are defined as semi-empirical since the physiological behaviour of the crops is not taken into account.

Semi-empirical water production functions that relate crop yield to the amount of water applied and evapotranspiration, have commonly been used to address water resource allocation problems. Since the depth of applied irrigation water and water consumed by crops represents water purchased by irrigators, most semi-empirical studies relating yield to water applied are of great concern to agricultural economists (Reca, et al., 2001; Bernado, 1985).

Various types of production functions have been used to address semi-empirical relationships between yield and irrigation water and evapotranspiration. For the purpose of this research, a typical water production function, generalised stepwise water production function and the Von Liebig water production functions have been discussed.

2.3.1.1 Typical crop water production function

This is the simplest water response function, and relates yield to different quantities of water applied as indicated by OS (in Figure 2.1) assuming that other input factors are fixed. With this relationship, production is assumed to be technically efficient when the maximum possible output is generated with a given set of inputs or when a selected output level is produced at minimum cost. All points on a crop water production function (curve) are regarded as technically efficient. Optimal yield is achieved where Y_1 corresponds with W_1. Below the curve, output level as marked by C, is sub-optimal, and output level above B is not attainable (Wichelns, 2002).

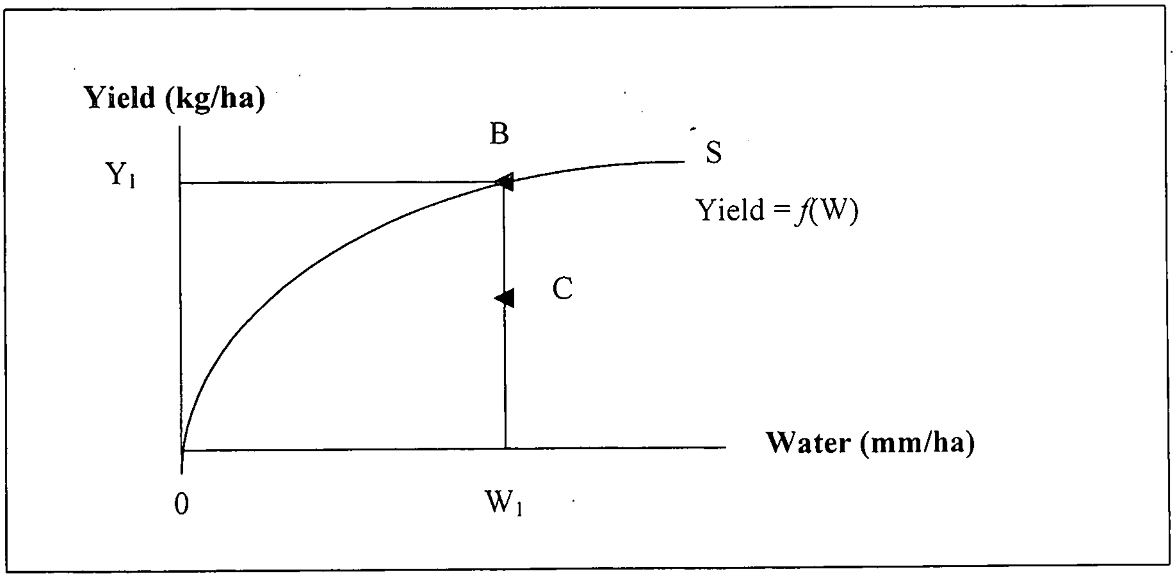

Figure 2.1: Typical crop water production function
(Source: Wilchens, 2002)

2.3.1.2 A generalised stepwise water production function

This is another form of presenting the relationship between irrigation water applied and yield. A generalised crop water stepwise production is shown in Figure 2.2. The production function is divided into linear segments, which show the amount of water applied with respective corresponding yield. An increase in the amount of water from W_0 to W_3 implies an increase in yield from Y_0 to Y_3.

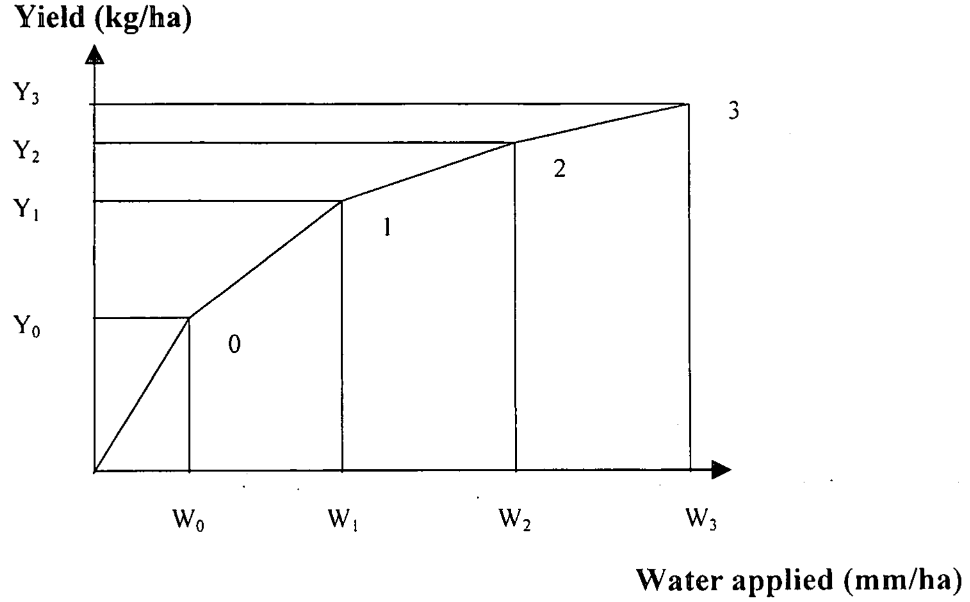

Figure 2.2: Generalised stepwise water production function
(Source: Kumar & Khepar, 1980)

In Figure 2.2, the maximum yield is attained where W_3 corresponds to Y_3, whereas the lowest crop yield occurs where W_0 meets Y_0. The zone between Y_0 and Y_3 is the rational zone for resource allocation. For efficient water allocation, a level of water use may be chosen anywhere between 0 and 3 where the marginal value of the product equals the price of water (Kumar & Khepar, 1980).

2.3.1.3 The Von Liebeg water production function

In the past studies relating yield to water applied, the main focus was on functional form, which allows for a growth plateau, such as Von Liebig following Liebig's law of the minimum (Llewelyn & Featherstone, 1997). The Von Liebig production function assumes that yield for a wide variety of crops increases linearly with irrigation water used by the crop until fixed maximum output is reached (Bogges et al., 1998). Beyond the maximum, yield remains the same and is subject to decrease due to poor soil aeration or drainage.

Figure 2.3 shows the Von Liebeg response curve when timing or water allocation is optimal and sub-optimal.

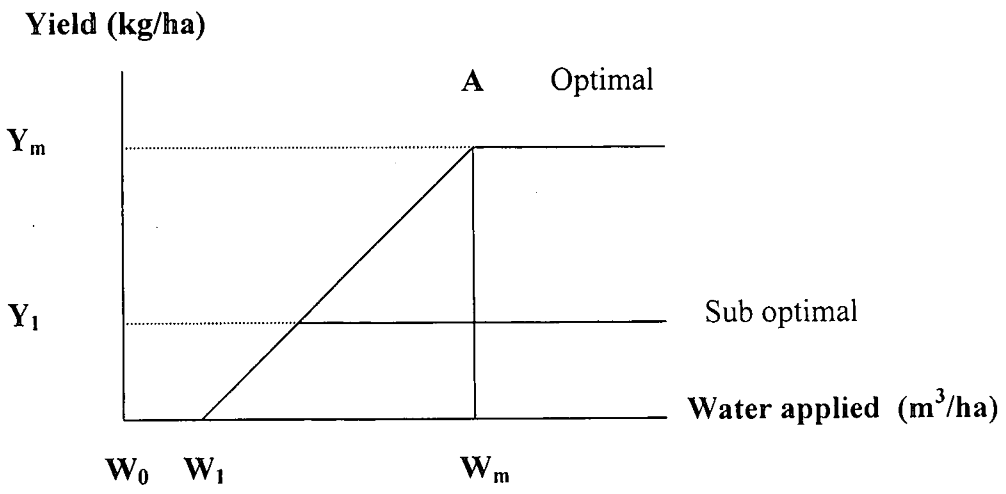

Figure 2.3: Optimal yield response to irrigation water application
(Source: Warrick & Gardener, 1983)

where :

W_0 no water application
W_1 initial water application
W_m maximum water applied
Y_1 Sub-optimal yield
Y_m maximum yield

The optimal curve results when timing and soil water is available to the plant when needed. Firstly, the soil profile must be saturated with water. Once the threshold (which is 15 mm to 20 mm) is exceeded, yield increases linearly to a maximum point A, where the available water is equivalent to evapotranspiration. Beyond the maximum yield (Y_m) which is achieved with maximum water application at (W_m), water is no longer regarded as a limiting resource and with more application of water constant yield is subject to decrease due to factors such as water-logging. Yield can be increased beyond the optimal point by considering other factors of production such as climate and soil conditions. For water application less than the threshold, no produce can be obtained (Warrick & Gardner, 1983). Below point A, there is sub-optimal water allocation. In this case, water is not allocated when needed hence the crops are deprived of water. To move from sub-optimal to optimal water allocation, frequency of irrigation has to be increased.

Several mathematical programming techniques including dynamic programming and multiple stage optimising techniques have been widely used to allocate scarce water. The objective of irrigation farmers is to optimise water resource use and maximise returns (Zhang & Oweis, 1999; De Juan et al., 1996 and Shangguan, 2000). A discussion of the LP technique as one of the techniques for allocating scarce water resources follows.

2.3.2 Linear programming technique in optimal allocation of resource

Linear Programming is a mathematical programming technique involving the use of a production function for determining the optimal allocation or utilisation of a farm's limited resources. This technique maximises or minimises a given objective function subject to a set of constraints. The LP consists of a linear objective function, linear constraints and a non-negativity constraint (Bender, Kahan, & Mylander, 1992).

According to Boles (1955), the essence of the linear programming technique for addressing the short-term allocation problem due to the farmer's limited ownership of water resources, involves comparing that allocation successively with alternative allocations and selecting the one that maximises farm returns. By so doing a Linear Programming technique can be used to solve water allocation problems, since it determines maximum returns to the most limiting resource. Furthermore, the model can accommodate as many variables as required by the researcher. The non-linear programming technique extends the LP approach to permit non-linear constraints.

The Linear Programming technique can be used to determine the marginal value product (MVP) of irrigation water, based on the marginal benefits derived from crop production or crop output to ensure efficient allocation of irrigation water (Conner, 1970). The value of irrigation water is discussed below.

2.3.3 The value of irrigation water

Solving the problem of determining the economic optimum level of input requires knowledge of responses in output to additional increment of water. Since the market value for irrigation water rarely exists, the MVP of water is defined as the amount that a rational user would be willing to pay for additional unit of water (Bernado, 1985). Willingness to pay is represented by the demand curve relating the quantity of good (water) demanded by producers at a series of prices.

The economic value of water can be derived from its uses, which vary with different users, location and time (Rogers, Bhatia, Huber & McKay, 1997). Since MVP is determined at the margin, after all the irrigation water available to the farm is utilised to its maximum, irrigation water can be allocated to its best use regardless of its price (Conner, 1970).

By determining the MVP of water based on output, farmers can maintain irrigation on existing cropping patterns or crop mixes so long as it is optimum or can cultivate crops that consume less water but which are profitable even when water is limited. Profit will be maximised when the MVP of water is equal to the price of water and reflects the best level of water farmers can purchase (Tiwari & Dinar, 2001; Khumar & Khephar, 1980). The MVP of water is very important as it measures the contribution of the water as input in crop enterprises.

The use of mathematical programming techniques and determining the MVP of an input (water in this case) are very important in determining the optimal allocation of the input.

2.3.4 Determining the optimum amount of irrigation water as an input

The important water allocation problem with regard to optimising irrigation water resources is to determine the amount of water required for any given crop output and returns that can accrue from it. According to Barret and Skogerboe (1980), economically optimal allocation of irrigation water can be derived from the slope of the total value product curve and total cost curve (generated from the economic maximising technique) when the production function is plotted as a function of water applied. The optimality condition is achieved where profit is maximised and the MVP of water as an input equals its unit price. The profit as a function of input can be expressed as follows:

$$\text{Profit} = P_y f(X) - P_x X$$

To maximise this function with respect to the variable input the derivative would be set at zero as follows:

$$\partial \text{Profit} / \partial X = P_y \, \partial Y / \partial X - P_x = 0$$

$$P_y MP_x - P_x = 0$$

$$P_y MP_x = P_x$$

$P_y MP_x$	is the slope of the Total Value Product (TVP) curve and is called the value of the marginal product (MVP).
X	is the variable input.
P_x	is the slope of the total cost function or the price of the input. Profit will be maximised when the slope of TVP equals the slope of the Total Cost (TC) curve (Doll & Orazem, 1984).
P_y	is the price of output y

MP_x is the marginal product of variable input X. It is the first derivative of the total production function taken with respect to the variable input X.

Since farmers operate under perfect competition in the market, the optimality condition is valid under the following assumptions:

- Producers have perfect knowledge of production relationships as well as input and output price relationships.
- The producer is a price taker.
- All firms' inputs and outputs are perfectly divisible.

2.3.4.1 Optimal condition under unconstrained water supply

The optimal seasonal irrigation water allocated is the water application required to equate the MVP of water with the price of applying a unit quantity of water including other inputs as indicated above.

2.3.4.2 Optimal conditions under constrained water supply

The profit maximisation problem is shown by introducing a constraint on the quantity of water available to the producers with the assumption that producers can purchase any quantity of the input at a fixed price (Bernado, 1985). On the farm, where a limited amount of input is used on several enterprises, producers will allocate each successive unit of input to the use where its marginal return, MVP, is the largest. For this situation to occur, the production function and production prices must be known for each enterprise. Inputs should be allocated to each enterprise in such a way that profit earned by the input is at a maximum and the marginal benefits of the input are equal in all enterprises. This can be expressed as follows:

$$MVP_{xa}=MVP_{xb}=MVP_{xc}=\ldots MVP_{xn}$$

Where:

MVP_{xa} is the marginal value product of X used on product A

MVP_{xb} is the marginal value product of X used on product B

MVP_{xc} is the marginal value product of X used on product C

N is the number of enterprises under consideration

The MVP of water is equal to the marginal cost of applying the unit of water and its scarcity value (Doll & Orazem, 1984).

After determining optimal allocation of resources, water in this case, sensitivity analysis can be carried out in order to determine the stability of the optimal solution. The sensitivity analysis is discussed below.

2.4. SENSITIVITY ANALYSIS

An important factor in determining the usefulness of an optimal plan developed/obtained for a farm is the sensitivity of the plan to price changes or input quantity changes (Swanson, 1955). According to Dent, Harrison and Woodford (1986), confidence and insights into water resource allocation can be gained in LP techniques through sensitivity analysis. With sensitivity analysis, LP can vary any one of the time, cost prices, resource supplied and input output coefficients, to find out how these changes affect optimal solution. The general rule is to vary one parameter at a time so that its effect on optimal solution can be measured easily. By means of parametric programming, the effect of changing applied water while holding other inputs constant can be measured. Parametric programming consists of the following components:

XPARAM = initial value of the variable parameter.

XPARMIN = the minimum value of the variable parameter.

XPARDELT = the size of the restriction by which the variable parameter has to be reduced or the parameter interval after which a solution is obtained.

2.5 SHORT COMINGS OF LINEAR PROGRAMMING TECHNIQUE

The main limitation of the LP optimisation model is that the objective functions are not really economic in nature and do not guarantee optimum allocation of water in deficit systems. LP is a short-term model whereas the water allocation process is continuous. The model cannot be used to formulate long-term water allocation decisions. To address these shortcomings, the LP model will be extended to Stochastic Dynamic Programming (out of the scope of this thesis) to accommodate long-term water allocation decisions.

The framework presented above focused on the maximisation of producers' profit, and deriving optimal water values in order to measure the contribution of water as an input into production processes. The next section deals with the methodological framework for optimising water resource allocation. Sub-objectives involved in the study are also addressed in this section.

2.6 METHODOLOGICAL FRAMEWORK

The study was conducted in an arid region, where irrigation plays a crucial role in crop production. To determine the importance of irrigation water or to find out whether it is worth irrigating crops, the financial position of a farm has to be determined. Water is one of the inputs, and its contribution (cost) forms part of the production costs that determine farm profit. Since irrigation water plays an important role in determining farm profitability, it should be optimally allocated to satisfy a given crop mixture subject to a given set of constraints.

In this section, the methodological framework for the research is discussed. The first part of the methodological framework deals with determining the financial position of a farm. Thereafter, the optimal allocation of irrigation water is discussed.

2.6.1 Determining a farm's financial situation

Figure 2.5 shows the methodological framework for analysing and interpreting a farm's financial situation. The framework consists of auxiliary statements, analyses and interpretations. The auxiliary statements can be compiled after collecting data by means of a questionnaire through farm visits. The schematic presentation of the farm management information system is shown in Figure 2.5

FARM MANAGEMENT INFORMATION SYSTEM

↓

AUXILIARY STATEMENT

- INVENTORY
- INCOME, RECEIPTS, EXPENDITURE, PAYMENTS
- PHYSICAL PRODUCTION DATA
- LABOUR RECORDS

↓

ANALYSES AND INTERPRETATION

- BALANCE SHEET ANALYSIS
  - Solvency
  - Liquidity
  - Net Worth
- INCOME STATEMENT ANALYSIS
- BALANCE SHEET/INCOME STATEMENT ANALYSIS
  - Capital turnover
  - Debt servicing ratio
- FARM SIZE ANALYSIS
  - Gross farm income
  - Total capital employed
  - Area of the farm
  - Land allocated to crops
- EFFICIENCY

Figure 2.5:– Farm Management Information System for analysing and interpreting financial situation

(Source: Van Reenen and Marais, 1992)

The farm management information system consists of auxiliary statements, which show inventory (a list of all assets available on the farm and how much they are worth), income, receipts, expenditure, payments, physical production data such as available land and labour records. From the auxiliary statements, income statements (shown in Figure 2.6) and balance sheet statements can be compiled and ratios derived to analyse the liquidity, solvency, profitability and efficiency of the farm and finally to interpret the farm's financial situation.

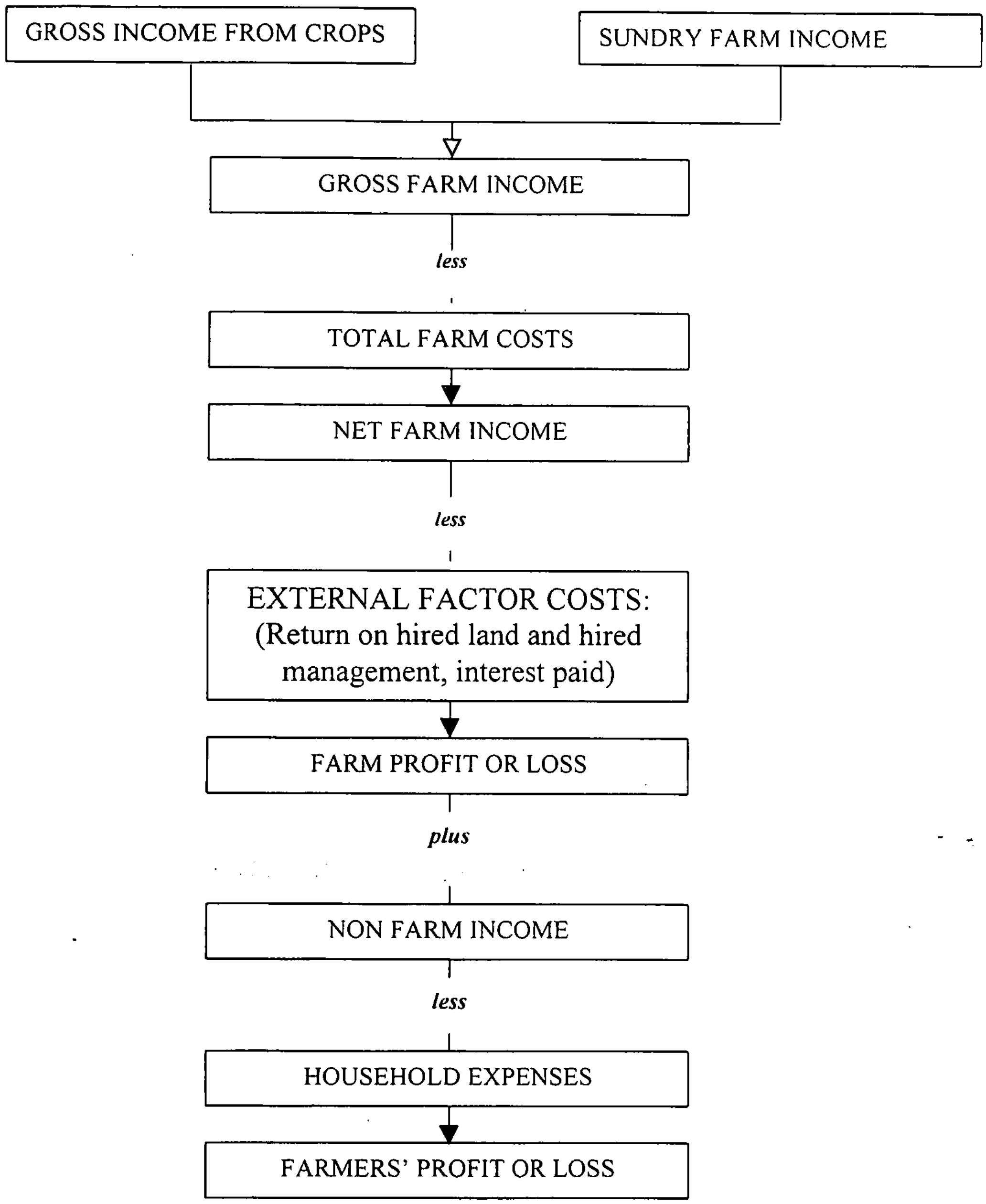

Figure 2.6: Schematic representation of the income statement of a farming enterprise

(SOURCE: Department of Agriculture and Water Supply) Directorate of Agricultural Production Economics, 1987

Figure 2.6 illustrates an income statement of a farming enterprise in determining farmers' profit or loss. First, gross income from crops and sundry income are added together to form gross farm income. Total farm costs are subtracted from gross farm income, resulting in net farm income. From net farm income, external factor costs such as returns on hired land or management are deducted in order to obtain the farmer's profit. Finally, non-farm income is added to farmer's profit and non-farm expenses (household expenses) are deducted, resulting in farm profit or loss.

2.6.2 Allocating irrigation water

This section deals with the methodological framework for allocating irrigation water. The methodological framework. The framework as illustrated in Figure 2.7 comprises of determining the inputs, mode of analysis and outputs anticipated for optimal allocation of irrigation water and utilisation of other inputs. The inputs involved in the study were obtained from various sources. The gross margin was obtained from the crop enterprise budgets. Information on tractor power, labour usage, land utilisation, and quantity of available water was gathered by means of a structured questionnaire. Finally, water requirements per crop were generated by the BEWAB irrigation system.

Before developing LP models, farms involved in the research were classified into three groups according to irrigation water rights namely small, medium and large farms. In each farm group, crop activities were divided into winter and summer season activities. Then, LP model was formulated for each season and for each farm group with a view to determining optimal resource utilisation for each crop mix and selecting the crop mix with the highest gross margin.

To calibrate LP model in order to reflect conditions in the study area, the LP test model was firstly formulated for each farm group. In the test model, various hypothetical scenarios were developed and run for the two seasons. A pilot survey was undertaken, whereby the results of the model were discussed with farmers in order to determine their preference on maximum area to maintain under cultivation for different cropping activities, and for what reasons. All the suggestions and corrections by the farmers were incorporated into the final LP model draft which was used to analyse different crop mixes.

The ultimate LP model was run for unconstrained and constrained water situations. Under the unconstrained irrigation water situation, the maximum water application that leads to the best economic returns (gross profit) was determined. The effects of changing crop prices were also analysed.

For constrained irrigation water availability, sensitivity analyses were carried out to determine the effect on optimal solution of changing crop output prices and decreasing available quantity of irrigation water. In this case, LP model was run parametrically to evaluate the response of crop mixes to water quantities, ranging from full application to certain reductions of full application. Crops that leave the optimal solution when water quantity decreases were noted. Then the optimal allocation of irrigation water, optimal cropping pattern/mix and MVP of water were determined for each crop mix. The output obtained was discussed with farmers and necessary corrections were made on the basis of farmers' preferences.

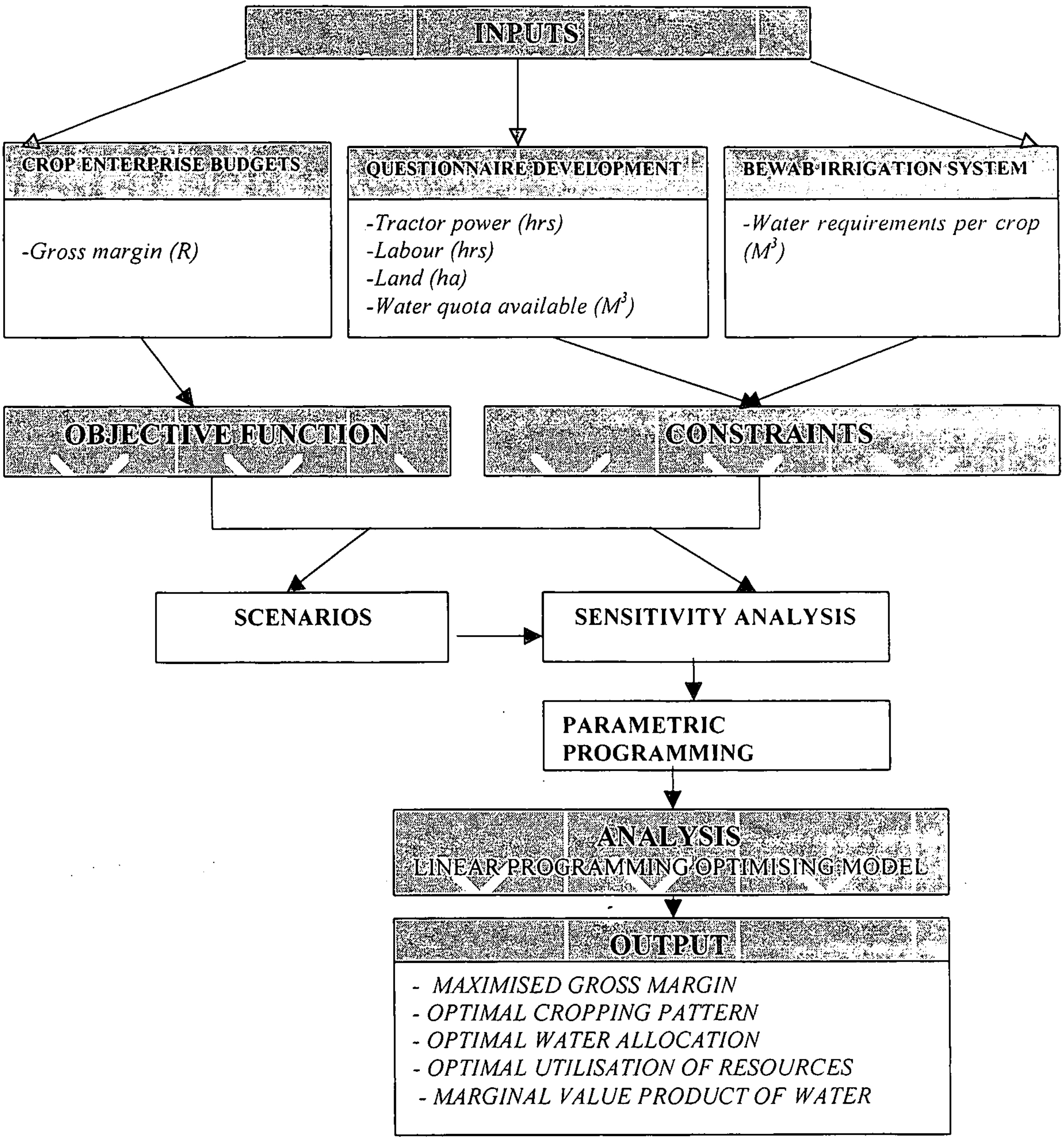

Figure 2.7: Methodological framework for optimal allocation of irrigation water

The methodology was achieved by pursuing the following sub objectives as indicated under research procedure.

2.7 RESEARCH PROCEDURE

In order to determine the financial situation of the farms and to optimally allocate irrigation water, the following objectives were identified:

Objective 1: To classify farms into different water-use groups and to describe the groups according to irrigation water rights.

A list of names of farmers, size of farms (area) with irrigation water rights, and channels leading to each farm in the research area were obtained. Then, the area with irrigation water rights for a particular farm was plotted against its respective farm to produce a graph. From the graph, farms involved in the study were classified into groups based on their irrigation water rights.

Objective 2: To determine whether economies of size exists in crop production.

Financial information was gathered by a questionnaire and used to determine economies of size for crop production. The following two financial statements were compiled to determine the financial situation:

- First, the income statement was compiled to show production costs and returns to crops produced on farms to determine net farm income and net farm profit.
- Secondly, the balance sheet was prepared to show assets and liabilities of the farms in order to determine their net-worth.

From income statements and balance sheets for different farm groups, different financial ratios such as solvency, liquidity, profitability and efficiency ratios were determined. The ratios were analysed to indicate whether or not economies of size exists.

Objective 3: To construct a Linear Programming model for different groups of farms to determine the impact of different water allocation regimes on farm decision making.

Before the LP model can be constructed, primary data required for the model was first identified and collected. Gross margins for various cropping activities was obtained from crop enterprise budgets. A questionnaire was developed to gather information on tractor power, labour and land usage and available water quantity allocated to each farm group per year. Through farm visits, information on constraints was obtained from personal interviews with farmers by means of a structured questionnaire prepared by the researchers. The questionnaire was completed as farmers responded to the questions asked. Information on water requirements per crop was obtained from the BEWAB irrigation system. In each farm group, farming activities were grouped into winter and summer season activities.

Two LP models, one for the summer season and the other for winter season, were developed for each farm group. The objective of the model was to maximise gross margin subject to the constraints namely, tractor power, labour usage, land required, total available water quantity and water requirements per crop activity. The models were run parametrically for the situation when water is unconstrained and when water is limited.

Objective 4: To derive optimal cropping mix to maximise farm net returns subject to different water resource allocation and use scenarios.

The gross margin obtained from the crop enterprise budgets was maximised using linear programming subject to the following constraints: maximum area allocated to each particular crop, crop water requirements, available water quantity, and tractor and labour hours required for each crop. To examine the economic consequences of limited water, the parametric programming technique was applied. The model was first run with the total (100 per cent) irrigation water allocation. Then, the total irrigation water allocation was reduced by 25 per cent, 50 per cent and 75 per cent. In each case, the optimal cropping pattern was determined.

Objective 5: To determine the marginal value product (MVP) of irrigation water as a proxy for water price in the study area.

The LP model was run in order to maximise gross margin subject to a given set of constraints. The maximised gross margin generated from the LP model was plotted against corresponding water applications in order to develop the total value product function of water. The total value product curve was presented in the form of linear segments, which show the amount of water applied with respective gross margin generated for a particular crop. By adding a linear trend line to each linear curve and determining the equation, the MVP of water was estimated for the short run. The MVP of water for winter and summer seasons were determined separately for each farm group and for each crop mix dealt with.

Objective 6: To determine water management strategies that farmers would employ when subject to different irrigation water reduction levels in the short, medium and long terms.

A questionnaire was used to gather information pertaining to farmers' reactions when the present irrigation water quota is reduced by 25, 50 and 75 per cent in the short, medium and long terms. Farmers were asked questions such as the type of crop mixture they will pursue, whether they intend to sell irrigation water when it is in surplus, and what they will do with the land if all the water available for irrigation is sold out to other water use sectors such as urban and industrial. The information gathered will assist in developing future water allocation strategies that farmers can use under serious water scarcity situations.

CHAPTER 3

DETERMINING REPRESENTATIVE FARM GROUPS AT THE RAMAH CANAL AT VANDERKLOOF DAM

3.1 INTRODUCTION

In chapter 1, a brief introduction of the research and research area was made. Chapter 2 presented the theoretical and methodological framework related to optimal allocation of irrigation water. In this chapter, the aim is to analyse crop farming situation on irrigated commercial farms on the Ramah Canal at Vanderkloof Dam with regard to existing irrigation water allocation and anticipated limitations on irrigation water availability. To achieve this, farms at Ramah Canal first need to be classified according to farm size, which will be representative of the area. Quantitative data is also required and will be acquired by means of a questionnaire. This information will be used to determine the financial position of farms and on-farm water allocation for irrigated crops produced. The classification of farms is discussed below.

3.2 PRE-SURVEY PREPARATIONS

3.2.1 Classification of farms

Before the main survey was executed, a list of all farms irrigated with water from Ramah Canal was obtained. It entailed among other things collecting names of farmers, the channel leading to each farm and the farm area with irrigation water rights. A total of 46 farmers were identified as irrigating 4 075 ha of land from Ramah Canal.

Three measures of central tendency: the mean, the median and the mode were calculated for the farms based on water rights each farm hold to provide a quick summary of results. The mean farm size was found to be 139 ha, the median was 126 ha and the mode was 60 ha. Neither the mean, the mode nor the median provided the best representation of the data when extreme values were dealt with. Hence, the three would not be used to classify the farms into groups.

To classify the farms in order to obtain the representative farm, the farms' irrigated area with water rights was first arranged in descending order. The area with irrigation water rights was then plotted against corresponding farms as shown in Figure 3.1. From Figure 3.1, farmers fall within three categories of less than 100 ha water rights farms (small), 100 to 200 ha water rights farms (medium), and more than 200 ha water rights farms (large).

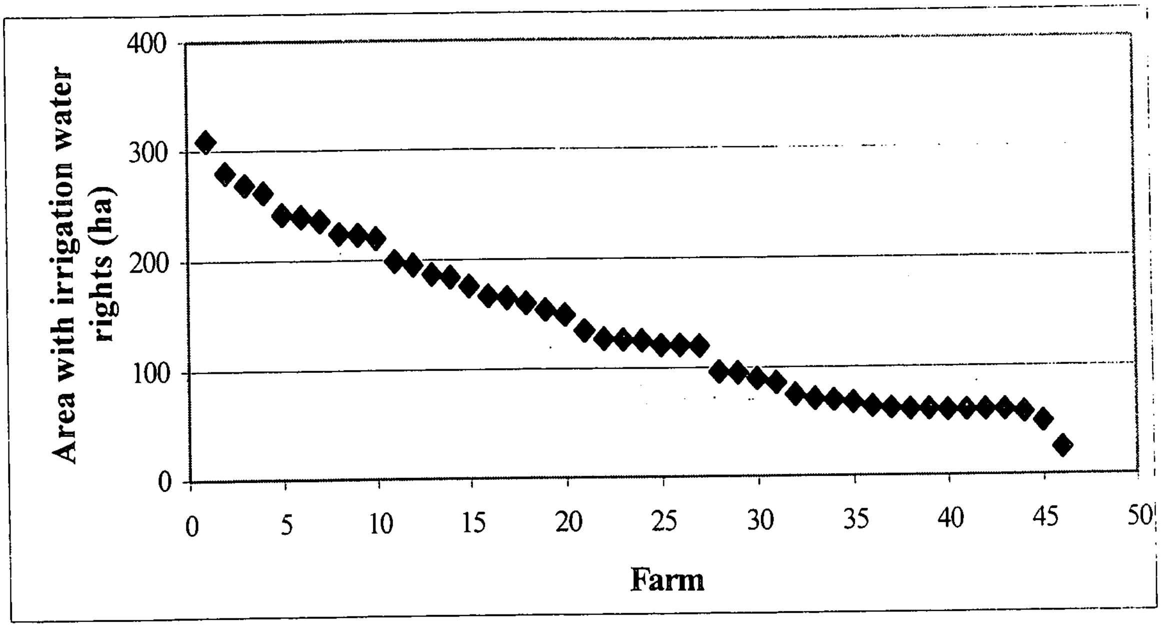

Figure 3.1: Farm groups according to irrigated area with water rights at the Ramah Canal, Vanderkloof Dam, 2000

For each group, ten farms were identified and the selected farmers were contacted by telephone for appointments. Out of 30 farmers contacted, 13 were not available for interviews. Hence, 17 farmers that were available for the interviews were classified into the three groups. The classification showed five farmers with less than 100 ha, five farmers with 100-200 ha and seven with more than 200 ha irrigation water rights. After classifying farms into different farm groups a questionnaire was developed to collect quantitative data.

3.2.2 Quantitative data collection

The questionnaire was developed and divided into two sections namely, section A and B. Section A consisted of farm assets and liabilities, farm expenditure (such as labour, repairs and maintenance, farm licences and insurance, additional farm expenditure) and household expenditure. This information is required to develop income and expenditure statements and balance sheet for executing financial analysis of the farms. Section B, focused on farm irrigation water allocation and strategies that farmers can use to manage irrigation water in the short, medium and long terms. Specifically, the following information was required in section B: available water quota for irrigation, how water is allocated to crops, area cultivated to different crops, average yield expected per crop produced, summer and winter crop rotations system and irrigation systems used in the research area. A complete questionnaire sample is attached in Appendix A. Crop enterprise budgets for different cash crops produced on the Ramah Canal were also developed (see Appendix B). When the questionnaire development has been completed, a pilot survey was organised to test it.

The pilot survey was first conducted on two farms, one with less than 100 ha and the other with greater than 200 ha of irrigation water rights. The farmers' suggestions were incorporated into the final questionnaire for the main survey.

3.3 MAIN SURVEY

The main survey was conducted from 13th to 15th November, 2000. Farmers were visited in their farms and the primary data needed was collected from personal interviews with the selected farmers. Questionnaires were analysed and the empirical results are discussed next.

3.4 EMPIRICAL RESULTS

3.4.1 Distribution of sampled farms according to irrigation water rights

Table 3.1 shows the farm size categories for the selected farmers. From Table 3.1, 44 per cent of the farms fall under large farm size category, 25 per cent under medium size farms and 31 per cent under small farm size category. The average size for the three farm categories is 75 ha, 180 ha and 240 ha respectively for the small, medium and large farms. One farmer from medium farm size group refused to provide full information requested. As a result, his questionnaire was discarded from the analysis. Thus, only four farms were analysed from this group. Crops that are produced in these farms and the area they occupy are discussed in section 3.4.2.

Table 3.1: Distribution of sampled farm sizes according to irrigation water rights at the Ramah Canal, Vanderkloof Dam, 2000

Farm Size Category	Area (ha)	Number of farms		Average Size (ha)
		Quantity	Percentage	
Small (<100 ha)	61 - 91	5	31	75
Medium (100 - 200 ha)	167 –196	4	25	180
Large (>200 ha)	220 –309	7	44	240
TOTAL		**16**	**100**	

3.4.2 Cropping mix

Table 3.2 shows the areas for crops produced in the study area. The total area occupied by the crops analysed is 4 075 ha. Large areas for maize and wheat potray that the two crops dominate the cropping activity in the area. Maize and wheat are produced and rotated on 3 200 ha or 78.5 per cent of the cultivated area. Lucerne follows in the third position with 300 ha. Crops that are also produced include potatoes, cotton, soyabeans, groundnuts, peas, beans, vegetables, onions, vineyards and pecanuts in decreasing order of their sizes.

Table 3.2: Cultivated area occupied by the crops produced at the Ramah Canal, Vanderkloof Dam, 2000

CROPS	AREA (ha)	PERCENTAGE
Maize	3200	78.53
Wheat	3200	78.53
Lucerne	300	7.36
Potatoes	160	3.93
Cotton	100	2.45
Soyabeans	100	2.45
Groundnuts	80	1.96
Beans/peas	40	0.98
Vegetables	40	0.98
Onions	20	0.49
Vineyards	20	0.49
Pecanuts	15	0.37
Total	**4 075**	**100%**

Source: Department of Water Affairs & Forestry at Vanderkloof Dam, 2000

After the farms have been grouped and the crops or crop mixes produced identified, the financial status of the three farm groups was determined in order to measure performance. To achieve this, income and balance sheet statements were compiled for the three farm groups. From the statements, different ratios were derived and analysed.

3.4.3 Analysis of farms' financial results

Farm managers use financial performance measures to assess the profitability, liquidity, solvency and financial efficiency of their farm business. These performance measures assist managers in making effective planning, implementation and control decisions needed to improve farms financial position and profitability. Performance measures are obtained from income statement and balance sheet, which summarise the financial position of the farm (Purdy and Langemeier, 1995). The income and balance sheet statements are compiled from farm records.

In this study, income statement and balance sheets are compiled for the three farm groups using average of five farms for less than 100 ha farms, four farms for 100 – 200 ha farms and seven farms for greater than 200 ha farms (Appendix C). Tables C1, C2 and C3 (Appendix C), provide income statements for less than 100 ha, 100 – 200 ha and more than 240 ha farm, respectively. In each income statement, the maximum, minimum and average gross farm income, total production costs, net farm income, farm profit and farmers' profit are calculated. In addition, farm efficiency (average income or costs divided by number of hectares available) is determined for each farm group.

The balance sheets are presented in Tables C4, C5 and C6 for less than 100 ha, 100 – 200 ha farms and more than 200 ha farm groups, respectively also in Appendix C. In each balance sheet, assets and liabilities are divided so that current, medium and long-term distinctions could be made.

Financial information showing average values drawn from income statement (see Table 3.3) and balance sheet (Table 3.4) was used to derive average solvency, liquidity, profitability and financial efficiency ratios in order to detect strengths and weakness within the farm businesses.

Table 3.3: Summary of income and expenditure statement showing average figures for less than 100 ha, 100 – 200 ha and more than 200 ha farms

VARIABLES	FARM SIZE (ha)		
	LESS THAN <100 ha	WITHIN 100 – 200 ha	MORE THAN 200 ha
Total gross farm income	716 170	2 128 690	2 667 145
Total production costs	603 313	1 836 072	2 071 847
Net farm income	112 857	292 619	595 298
Farm profit	55 444	59 594	418 681
Farmers profit	-26 796	-65 411	292 311

Table 3.4: Summary of balance sheet statement showing average figures for less than 100 ha, 100 – 200 ha and more than 200 ha farms

VARIABLES	FARM SIZE (ha)		
	<100 ha	**100 – 200 ha**	**>200 ha**
LIABILITIES			
Current liabilities	482 540	611 250	1 354 122
Medium term liabilities	109 602	669 333	711 800
Long-term liabilities	353 232	1 095 515	315 590
Total Liabilities	830 887	1 934 886	2 084 972
ASSETS			
Current assets	740 542	1 174 775	2 224 015
Medium-term assets	850 371	1 339 225	2 265 198
Fixed assets	1 946 906	4 391 250	7 706 933
Total assets	3 537 818	6 905 250	12 094 991
Net worth	2 706 932	4 970 364	10 010 019

Table 3.5 outlines average financial ratios for small farms, medium and large farms. The derived ratios are based on average of five farms for small farm group, four farms for medium farm group, and seven for the large farm group.

Table: 3.5 Financial ratios for the farms analysed at the Ramah Canal, Vanderkloof Dam, 2000

TYPE OF RATIO	FARM SIZE (ha)			NORM (BENCHMARK)
	<100	100 – 200	>200	
Solvency ratios				
Net capital Ratio	4.26:1	3.57:1	5.80:1	≥2:1
Leverage ratio	0.31:1	0.39:1	0.21:1	≤1:1
Own capital ratio	0.77:1	0.72:1	0.83:1	≥0.5:1
Liquidity ratios				
Current ratio	1.53:1	1.92:1	1.65:1	≥2:1
Intermediate ratio	2.69:1	1.96:1	2.18:1	≥4:1
Working capital	258 002:1	563 525:1	872 893:1	
Profitability				
Farm profitability	3%	9%	5%	
Profitability on own capital	2%	8%	4%	
Efficiency ratios				
Cost ratio	0.84:1	0.70:1	0.78:1	≤0.5:1
Fixed assets turnover	0.37:1	0.48:1	0.35:1	≥0.5:1

3.4.3.1 Solvency ratios

Solvency measures the amount of debt and other expense obligations used in the farm business relative to the amount of owner equity invested in the business (Van Zyl, Kirsten, Coetzee and Blignaut, 1999). Solvency ratios indicate the business ability to repay all financial obligations if all assets are sold. They also provide an indication of the ability of the farm to continue operations as a viable business. The more the assets exceed liabilities the more solvent the farm is and liable for greater loan capital for its effective functioning. The most commonly used solvency ratios are net capital ratio, leverage ratio and own capital ratio.

a) Net capital ratio

Net capital ratio compares the total assets to the total liabilities to find out if farmers will be in a position to meet liabilities when assets are sold. A ratio of 2:1 is regarded as a norm or benchmark (Van Zyl et al, 1999). In Table 3.5, all the three groups are highly solvent because their solvency ratios exceed 2:1. This implies that farmers can meet their liability obligations if all farm assets are sold.

b) Leverage ratio

The leverage ratio measures the degree to which a farmer will be able to meet total liabilities by using his own capital. As a norm, a ratio of less than 1:1 is highly acceptable and shows a farm with a healthy capital position (Van Zyl et al, 1999). From Table 3.5 leverage ratios averaged 0.31:1, 0.39:1, and 0.21:1 respectively for small farms, medium farms and large farms respectively. This implies that, for example, an average small farm uses R0.31 outside capital for every R1.00 invested in farm business. Therefore, the farms are in good leverage position and can meet their debt repayments.

c) Own capital ratio

Own capital ratio measures the proportion of total farm assets financed by the owner's equity. It is the ratio between farmer's contribution and total assets. The higher the ratio, the more total capital has been supplied by the owner and the less capital supplied by creditors. As a norm, a ratio of at least 0.50:1 is regarded as desirable (Van Zyl et al, 1999). Table 3.5 shows that large farms have the highest average own capital ratio at 0.83:1 indicating that an average farm provides R0.83 of own capital for every R1.00 of total assets invested in the business. Small farms are next with an average ratio at 0.77:1. Medium size farms have the lowest own capital ratio on average of 0.72:1. All the three farm groups are in good solvency condition as their own capital ratios well exceed the benchmark of 0.50:1.

3.4.3.2 Liquidity ratios

Liquidity measures the ability of the farm business to meet financial obligations as they come due without disrupting the normal operations of the business (Purdy and Langemeier, 1995). It shows the ability of the farm business to quickly generate cash to pay its debts. Liquidity measures commonly used in farm business include current ratio, intermediate ratios and working capital

a) Current ratio

Current ratio indicates the extent to which the farm business can generate cash in the short run to redeem current liabilities (Van Zyl et al, 1999). As a norm, a ratio of at least 2:1 is desirable. Table 3.5 shows that current ratio averaged 1.53:1, 1.92:1 and 1.65:1 respectively for small, medium and large farms. This means that the current assets worth R1.53, R1.92 and R1.65 respectively are available for small farms, medium farms and large farms to redeem every R1.00 of current liabilities. Small farms stand a high risk of being liquidated because of low ratio compared to the other two groups.

b) Intermediate ratio

Intermediate ratio is the ratio of the sum of current and medium term assets to the sum of current and medium term liabilities. As a norm a ratio of 4:1 is an indication of a well performing farm. In Table 3.5, small farms have the highest average intermediate ratio of 2.69:1, while medium farms have the lowest average intermediate ratio at 1.96:1. Large farms lie between the two farm groups with an average intermediate ratio of 2.18:1. The ratios indicate that for example, an average small farm has R2.69 of current and medium term asset for every R1.00 of current and medium term liability. The liquidity position of the three farms is not good enough for them to redeem both current and medium term liabilities.

c) Working capital

Working capital is a measure of the amount of funds available to purchase inputs and inventory items after selling all current assets and repaying all current farm liabilities (Purdy and Langemeier, 1995). Working capital averaged R258 002, R563 525 and R872 893 respectively for small, medium and large farms. This means that on average a small farm has R258 002 to purchase inputs after selling all current assets and repaying all current liabilities. The working capital for the three farm groups is good since it is positive.

3.4.3.3 Profitability ratios

The profitability ratios are used to demonstrate the success of the farm business. The ratios under this category include:

a) Farm profitability

Farm profitability is calculated by expressing net farm income as a percentage of average total capital employed (Van Zyl et al, 1999). From Table 3.5, small farms have an average farm profitability of three per cent indicating that for every R100 of total capital used in the farm business, farmers earn R3.00 as profit. Medium farms have farm profitability percentage of nine per cent. Lastly, farm profitability stood at five per cent for large farms.

b) Profitability on own capital

Profitability on own capital indicates interest return the farmer earns on own capital after borrowed capital has been paid (Van Zyl et al, 1999). Profitability on own capital averaged 2 per cent, 8 per cent and 4 per cent respectively for small, medium and large farms indicating that for example, an average small farm earns R2.00 of profit for every R100 invested in farm business. The profitability on own capital is less than the profitability on total capital employed indicating that farmers have to use own capital to meet interest and liabilities.

3.4.3.4 Efficiency ratios

Efficiency measures how assets or resources are applied in farm business to achieve low costs of production (Van Zyl et al, 1999). Efficiency ratios indicate how effectively assets are used in the farming business. The most commonly used ratios are cost ratio and fixed assets turn over.

a) Cost ratio

Cost ratio indicates the ratio between total expenditure and gross farm income. As a norm, a cost ratio of less than 0.50 is regarded as desirable (Van Zyl et al, 1999). In Table 3.5, the cost ratios for the three farm groups are indicated. On average, the expenses amounting to R0.84, R0.70 and R0.78 respectively for small, medium and large farms are claimed in every R1.00 of income. The much higher cost ratio in small farm group may be due to the fact that some farmers have incurred high expenses when purchasing perennial crops and some assets associated with them. To improve the ratio, farmers must pay off debt and increase total area under production.

b) Fixed assets turn over

This is the ratio between the income and fixed assets. It indicates how well the farm business is using its fixed assets to generate sales. As a norm, a ratio of at least 0.50:1 is desirable. Small farms have a ratio of 0.37:1, medium farms have a ratio of 0.48:1 and large farms have a ratio of 0.35:1 on average. This means that for example, an average small farm has R0.37 of fixed assets to generate every R1.00 of sales. The ratios for small farms and large farms are low indicating that there is over investment in farm fixed structures such as buildings and equipment.

3.4.4 Summary

Income statements and balance sheets were prepared for the three farm groups. From the two performance measures, different ratios were derived. From the above financial analysis, it was found that medium size farms are the most efficient in the production of various crops as indicated by the highest gross farm income per crop per hectare; the highest net farm income; and highest farm profit per hectare. The high efficiency status of the medium farms is also indicated by the cost ratio, which is the least of the three farm groups and the highest fixed assets turnover. Although the solvency position of this group is the least, the farms have the highest liquidity position on average as indicated by farm profitability and profitability on own capital which are greater than those of the two farm groups.

Large farms are the second most efficient with the second highest net farm income and farm profit per hectare. The large farms have the highest solvency position on average as indicated by net capital ratio, leverage ratio and own capital ratio. Most of the assets in large farms are fixed as indicated by low liquidity ratios. This implies that the assets are not used efficiently to generate enough sales with consequent low fixed assets turnover. Inflow and outflow of funds in the short and medium terms are not good enough hence farmers can experience cash flow problems, which in the long run can render farming business insolvent.

The least performing group are the small farms as indicated by their least efficiency status. The group has the least profitability status and incurs the highest expenses as indicated by the cost efficiency ratio. The reason for this may be that some small farmers had to spend much income in establishing perennial crops because the current mix of cash field crops does not generate enough income to cover all expenses. The group has the highest intermediate ratio and the second highest current ratio meaning that it has the potential to redeem both short and medium term liabilities in time and look for possibilities of making profit or expanding farm business. By increasing production on perennial crops, the group can be in a position to make profit.

The above sections (section 3.1 to 3.5) have focused on determining representative farm groups and analysing the financial performance of such groups. The next section deals with on-farm water allocation and water management strategies, which farmers would apply if water scarcity persists in the area.

3.5 ON-FARM WATER ALLOCATION FOR FARMS IRRIGATED IN THE RAMAH CANAL AT VANDERKLOOF DAM

This section deals with the on-farm water allocation by the BEWAB irrigation scheduling model. Each farm that is irrigated with water from Ramah Canal at Vanderkloof Dam is allocated 11 000 m^3 of water per hectare of irrigated area with water rights. The water is allocated to crops according to irrigation scheduling model called BEWAB developed by Bennie, Coetzee, Van Antwerpen, Van Rensburg and Du T. Burget (1988). The data requirements for the model include the type of crop, length of growing season, target yield, depth of the soil; silt plus clay content for 200 mm depth and the selected rain storage capacity. The water application to each crop depends on the target yield set for the crop from the upper boundary of water production functions based on historic water use-yield relationships. The daily crop water requirements is estimated from relative crop water demand curves (Bennie, 1991). The output for the model is divided into categories of irrigation scheduling, namely:

- Complete partial crop water demand (CWD) addition during peak consumption and end season with dry soil;
- Profile when planted completely wet and end season with dry soil;
- Profile when planted partially wet and end season with dry soil; and
- Profile when planted completely dry and end season with dry soil.

The output of this model in Table 3.6 below provides inputs into the LP model in the form of monthly water requirements by crops per unit area (ha).

Table 3.6: On-farm irrigation water allocation by BEWAB irrigation scheduling system at the Ramah Canal, Vanderkloof Dam, 2000

Days after Planting	Complete CWD addition during peak		Profile completely wet when planted		Profile partially wet when planted		Profile dry when planted	
	IRR (mm)	Total (mm)	IRR (mm)	Total (mm)	IRR (mm)	Total (mm)	IRR (mm)	Total (mm)
10	9	9	9	9	6	6	6	6
17	15	24	15	24	39	44	39	44
24	23	47	23	47	39	83	39	83
31	31	78	31	78	39	121	39	121
38	37	115	37	115	39	160	39	160
45	42	157	42	157	39	199	39	199
52	46	204	46	204	39	237	39	237
59	50	254	50	254	39	276	39	276
66	53	307	53	307	39	315	39	315
73	55	362	54	361	52	367	52	367
80	57	419	54	415	54	421	54	421
87	57	476	54	470	54	475	54	475
94	57	533	54	524	54	529	54	529
101	57	590	54	578	54	583	54	583
108	55	645	54	632	54	638	54	638
115	53	698	53	685	53	691	53	691
122	50	749	50	736	50	741	50	741
129	47	796	47	783	47	788	47	788

(Source: BEWAB, 1988)

where:

CWD : Complete partial crop water demand

IRR : Irrigation water

Table 3.6 shows an outlay of BEWAB results including days after planting a crop, amount of irrigation water in millimetres (IRR, mm) applied on weekly basis and cumulative total irrigation water (Total, mm) applied per week for the four categories of irrigation scheduling. According to Bennie (2001), farming in the Ramah Canal can be classified under the third category of irrigation scheduling whereby crops are planted when the soil profile is partly wet and ends with dry soil profile after harvesting. Under this category at least two crops can be produced per year (one in winter and the other in summer crops) depending on the irrigation water rights a farmer holds.

3.6 CONCLUSION

The financial positions of the farms were analysed based on solvency, liquidity, profitability and efficiency status of the farms. The solvency status of the three farm groups is very good. This is indicated by the net capital ratios, which are above the benchmark of two or above, the leverage ratios which are below the norm of 1 and own capital ratios which are above a benchmark of 0.5. This implies that the farms in three farm groups have more assets than liabilities.

The liquidity status of the farms as explained by current ratio and intermediate ratios is very poor. The current and intermediate ratios of the three farm groups are below the norm of two and four, respectively. This implies that although farmers possess a lot of assets, they do not generate enough cash to redeem short-term liabilities. If these liabilities keep on piling in, farmers would encounter serious financial problems such as bankruptcy in future.

The profitability status of the farms is not satisfactory. The profitability on own capital is less than profitability on total capital employed (farm profitability). This means that farmers are encountering negative leverage and as a result have to use their own capital in order to meet interest and other liabilities.

The efficiency status as indicated by the cost ratio and the fixed turn over is very poor. The cost ratio for the three farm groups is far above the benchmark, which is 0.50 or less. Also, the fixed assets turnover for the three is below the benchmark or the norm which is 0.50.

Since the farm groups are highly solvent it implies that farmers can improve financial status of the farms by converting fixed assets into current assets. By so doing, the current assets can be used to redeem the current liabilities and improve the liquidity status of the farms. Consequently, the profitability of the farm business will also improve. Other possible measures can be to reduce production on low value crops such as maize, which is the dominant crop in the area.

The financial analysis also shows the existence of economies of scale. From the analysis. the medium farm group can be regarded as the optimal farm size to operate on, in order to gain better profit whereas small farm group is the least efficient. By changing production practices to high value crops for example, it is assumed that small farmers would be in a position to generate profit from a small unit of land which, will redeem liabilities and improve profit. If profit is generated, this means that water is used efficiently as the resource is a major input in farming in the study area.

CHAPTER 4

THE LINEAR PROGRAMMING MODEL

4.1 INTRODUCTION

Linear Programming (LP) is a mathematical optimising technique, which seeks to maximise or minimise an objective function subject to a given set of constraints. LP is preferred to other mathematical optimising techniques such as dynamic programming because of its flexibility in handling a large number of constraints (Reca, et al. 2001). In this chapter, the development and application of linear programming model are discussed. The sensitivity analysis performed on selected variables is also discussed.

4.2 FORMULATION OF THE LINEAR PROGRAMMING MODEL

A linear programming model was developed and applied to the three identified farm groups namely, 75 ha, 180 ha and 240 ha farms. The aim is to determine the optimal cropping pattern that gives the maximum net returns at different irrigation water availability levels and also to determine the short-term value of irrigation water. The following set of constraints was identified namely, labour, land, tractors power, water and capital. It was found that out of the constraints identified above, the size of available irrigable land and the amount of irrigation water were the most important constraints in the study area. Other constraints although outside the scope of the study, were also considered so as to leave no stone unturned. Therefore, the optimum amount of labour and tractor hours that could be employed were determined for each farm group.

The model consisted of three main components namely:

i) Linear objective function for maximisation of gross margin

ii) Linear constraints

iii) Non-negativity constraints

The description and mathematical formulation of each LP component are given below. The objective function of the model is described first whereafter, the constraints are described next.

4.2.1 Objective function

The main objective of this study is to maximise farm profit. The gross margin is used as an indicator of profit. Therefore, it is assumed that maximisation of profit is equivalent to maximisation of gross margin. The per hectare gross margin is obtained from the year 2000 crop enterprise budgets developed by the Department of Agriculture in Northern Province and the University of the Free State. The objective function aggregates gross margin over total area cultivated per farm group over the winter and summer seasons. A total of six crops are involved in the study namely wheat, maize, lucerne, groundnuts, cotton and potatoes. Wheat is cultivated in winter season and the rest of the crops in summer. Although lucerne is a perennial crop, it consumes 90 per cent of its water in summer, hence it is taken as summer crop. The objective function of the model is stated as follows:

$$Max Z_{fs} = \sum_{i=1}^{6} G_i X_i \qquad (1)$$

where:

i	=	1,2,3,…,6	Crops
f	=	1,2,3	Farm groups
s	=	1,2	Seasons
s=1	=	summer season	
s=2	=	winter season	
Z_{fs}	=	the total gross margin for farm groups f during season s.	
G_i	=	per hectare gross margin of crop activity i	
X_i	=	area planted to crop i	

Table 4.1 shows gross margin for the crops generated from crop enterprise budgets. From Table 4.1 maize has the least gross margin of R758.37/ha whereas potatoes have the highest gross margin of R16 215.06/ha. The crop margin for other crops range between R2 000/ha to R3 000/ha.

Table 4.1: Gross margin generated from crop enterprise budgets at the Ramah Canal , Vanderkloof Dam, 2000

CROPS	GROSS MARGIN (R/ha)
Maize	758
Cotton	2 152
Wheat	2 308
Lucerne	2 720
Groundnuts	2 983
Potatoes	16 215

The objective function is subject to the following linear constraints namely land, labour, water and tractor hours. An upper limit is placed on the availability of these constraints in accordance with the amount available in each crop combination. In addition, the constraints are divided into monthly requirements.

4.2.2 Constraints

4.2.2.1 Land constraint

The cultivated area of the Ramah Canal is about 6 000 ha. Maize and wheat are the major cultivated crops in the area (Rossouw, 2000). Other crops are produced in small margin compared to the two major crops. The farms involved in the study are grouped in three farm sizes on the basis of irrigated area with water rights. With this grouping, three distinct average farm sizes emerge namely 75 ha, 180 ha and 240 ha sizes categorised as small, medium and large farms, respectively (see Figure 3.1).

A survey was conducted after classifying farms in order to collect necessary data for the research from each farm group. The data collected was analysed and the first set of results were discussed with farmers in order to determine their preference on the area to cultivate different crops, and for what reasons in order to subject crop area constraint to the model. During the discussion, it became clear that farmers aim at producing at least three crops in two years, that is at least two summer crops and one winter crop have to be cultivated. The cropping mix (crop area) restrictions imposed on the model following the discussions with the farmers are presented below.

According to the farmers, the maximum production area under wheat and maize depends on irrigation system used, namely centre pivot irrigation system, which irrigates in multiples of 60 ha. In addition, farmers prefer not to reduce the existing area under the two crops so as to be able to meet their market needs. Consequently, the present use of irrigated land for maize and wheat follows the pattern in which the two crops are rotated on 60 ha, 120 ha and 180 ha respectively for small, medium and large farms. The rest of the available land can be planted to other crops under sprinkler irrigation system.

The use of available land by different crops throughout the year is indicated in Table 4.2. From Table 4.2, almost all irrigated land is fully utilised throughout the year with the exception of July, August and September months when lucerne is not cultivated and the land can be prepared for groundnuts, cotton or potatoes cultivation.

Table 4.2: Land occupation in months by different crops at the Ramah Canal, Vanderkloof Dam, 2000

Crops	Land occupation in months
Wheat	July to December
Maize	December to June
Groundnuts	October to April
Cotton	October to May
Potatoes	October to April
Lucerne	Perennial

Land allocation for different farm groups is presented as follows:

a) Land allocation on 75 ha

When 60 ha of cultivated land is allocated to maize, the rest of the land can be planted either to lucerne, groundnuts, cotton or potatoes. These result in production of two summer crops and one winter crop.

b) Land allocation on 180 ha

The use of land on 180 ha farm depends on the number of crops farmers want to cultivate in summer. If farmers intend producing three summer crops that is, maize and the two other crops, 120 ha can be allocated to maize and the rest of 60 ha shared equally among the other two crops. But, where the target is to produce two summer crops, area allocated to maize will remain the same whereas the rest of the land, 60 ha can be allocated to another summer crop.

c) Land allocation on 240 ha

Land allocation conditions for 180 ha also apply to 240 ha. The only exception is that, maize and wheat can be rotated on 180 ha and not on 120 ha as is the case with 180 ha farms. When lucerne is not cultivated, there is a possibility that farmers can allocate full-cultivated area to wheat after harvesting summer crops.

Table 4.3 illustrates how land constraint is included in the matrix for six crops considered in the research. The first row shows total available land which can either be 75 ha, 180 ha or 240 ha depending on the farm size a farmer is operating on. The next rows show land allocation to individual crops. The upper limit for the total available land and for individual crops is denoted by X because it varies according to the size of available irrigated land per farm group.

Table 4.3: Land allocation to crops at the Ramah Canal, Vanderkloof Dam, 2000

ACTIVITY	AREA ALLOCATED PER CROP (ha)						Upper Limit
	Wheat	Maize	Lucerne	Groundnuts	Cotton	Potatoes	
Total land available	1	1	1	1	1	1	X
Wheat	1						X
Maize		1					X
Lucerne			1				X
Groundnuts				1			X
Cotton					1		X
Potatoes						1	X

The land constraint (see Equation 2) stipulates that the total land area required to produce all six crops should be less or equal to the available land for each season.

$$\sum_{i=1}^{6} X_i \leq L_s \qquad \text{..(2)}$$

where:

L_s = the total available land for production in summer and winter seasons

i = 1 for wheat in winter season

i = 2 to 5 for maize, lucerne, groundnuts, cotton and potatoes in summer

X_i = area planted to crop i

4.2.2.2 Labour constraint

Labour requirement of each crop is expressed in hours per hectare for each month as obtained from Myburgh (2000) and is computed as the sum of labour needs for all cropping activities per year. Two types of farm labourers, full-time and part-time labourers are normally used in all farms. Full time labourers are hired on permanent basis to do various farming activities throughout the year hence are available for every month of the year. Part-time or casual labourers are hired when there is too much farm activities to be done within a limited or specified period of time such as during harvesting time. But, when there is not much work to do on the farm such as in winter, full time farm workers normally do household work and engage in non-farm activities. Very few farm workers are hired on permanent basis. Thus, about two, three and six permanent labourers are hired for small, medium and large farms respectively.

On the average, all farm labourers are expected to work for eight hours per day for 20 working days per month making a total of 160 labour hours per month or 1 920 hours per year. Small farms have two regular labours that is, 320 regular labour hours are available per month or a total of 3 840 hours per year. Medium farms have three regular labourers or 480 labour hours per month amounting to 5 760 labour hours per year. Large farms have six regular labourers or 960 labour hours per month, which make a total of 11 520 hours per year.

The labour constraint requires that the amount of labour hours to be hired for the production each of the six crop enterprises in a year should be less or equal to the total available labour hours. The mathematical formulation of the constraint is as follows:

$$\sum_{i=1}^{6}\sum_{j=1}^{12} d_{ij} X_i \leq N \quad \text{.....(4)}$$

where:

d_{ij} = per hectare labour hours needed for crop i in month j

X_i = area planted to crop i

N = total labour hours available

Table 4.4 below shows monthly labour hours required by different crop enterprises. The upper limit (X) indicates the total labour hours available per month per farm group.

Table 4.4: Monthly labour hours required per hectare per crop at the Ramah Canal, Vanderkloof Dam, 2000

MONTH	LABOUR HOURS REQUIRED PER CROP						Upper Limit
	Wheat	Maize	Lucerne	Groundnuts	Cotton	Potatoes	
January	0.00	1.00	5.86	0.00	8.00	0.64	X
February	0.00	0.00	5.86	0.00	8.00	1.28	X
March	0.00	0.00	5.86	0.00	8.00	0.64	X
April	0.00	0.00	5.86	96.00	0.00	230	X
May	0.00	0.00	0.00	80.00	8.00	0.00	X
June	2.73	0.00	0.00	0.00	0.00	0.00	X
July	2.68	1.06	0.00	0.53	0.53	0.53	X
August	0.64	0.00	1.60	0.53	0.53	1.67	X
September	0.00	0.00	5.86	2.20	2.20	0.53	X
October	0.00	0.00	5.86	4.20	3.84	26.7	X
November	0.00	0.00	5.86	0.00	1.00	1.64	X
December	0.00	6.93	5.86	1.33	9.32	0.64	X

4.2.2.3 Tractor power constraint

Tractor power constraint is also expressed in hours per hectare for each month as obtained from Myburgh (2000). Tractor hours for a particular farm group are limited according to the total number of tractors available in the farm group and the working hours per day. It is assumed that each tractor can work for eight hours per day for 20 working hours per month. These amount to a total of 160 tractor hours available per month per tractor or 1 920 tractor hours available per year per tractor.

Farmers in the three identified farm groups own different number of tractors. On average, farmers belonging to 75 ha farm own three tractors or have 480 hours available per month, which make a total of 5 760 hours available per year. Medium farms have at their disposal an average of four tractors per farm making a total of 640 tractor hours per month or 7 680 hours per year. Large farms own six tractors per farm making 960 hours per month or a total of 11 520 hours per year.

Table 4.5 shows tractor hours required by different crop enterprises per month. The upper limit (X) indicates the available tractor hours per farm group.

Table 4.5: Monthly tractor requirements per hectare by different crops at the Ramah Canal, Vanderkloof Dam, 2000

MONTH	TRACTOR POWER REQUIRED PER CROP (hours)						Upper Limit
	Wheat	Maize	Lucerne	Groundnuts	Cotton	Potatoes	
January	0.00	1.00	5.33	0.00	0.50	0.32	X
February	0.00	0.00	5.33	0.00	0.00	0.64	X
March	0.00	0.00	5.33	0.00	0.00	0.32	X
April	0.00	0.00	5.33	8.00	0.32	16.00	X
May	0.00	0.00	0.00	17.6	0.00	0.00	X
June	2.73	1.00	0.00	0.00	0.00	0.00	X
July	0.67	0.53	0.00	0.53	0.53	0.53	X
August	0.32	0.00	0.80	0.53	0.53	1.67	X
September	0.00	0.00	5.33	2.20	2.20	0.53	X
October	0.00	0.00	5.33	1.21	1.12	2.67	X
November	0.00	0.00	5.33	0.00	1.00	1.32	X
December	0.00	3.94	5.33	2.66	1.32	0.32	X

The tractor hour constraint states that the required tractor hours to produce crops should be less or equal to the available tractor hours. The mathematical formulation for tractor hours can be stated as follows:

$$\sum_{i=1}^{6}\sum_{j=1}^{12} c_{ij} X_i \leq B \qquad \text{.....(5)}$$

where:

c_{ij} = per ha tractor hours needed to produce crop i in month j

X_i = area planted to crop i

B = the total tractor hours available

4.2.2.4 Water requirement constraint

A water quota of 11 000 m^3 per hectare is allocated annually to each farm based on area with irrigation water rights for the farm. The water quota is allocated to crops according to BEWAB irrigation scheduling system. Monthly crop water requirements as generated by the BEWAB are shown in Table 4.6.

Table 4.6: Monthly water requirement per hectare per crop at the Ramah Canal, Vanderkloof Dam, 2000

MONTH	WATER REQUIRED PER CROP PER HA (m^3/ha)					
	Wheat	**Maize**	**Lucerne**	**Groundnuts**	**Cotton**	**Potatoes**
June						
July	630					
August	1 110					
September	1 170		1 500			
October	1 540		2 250	850	800	490
November	1 510		2 250	1 640	1 510	790
December		960	2 250	1 680	1 200	990
January		1 900	2 250	1 690	1 790	1 480
February		2 060	2 250	1 740	2 180	700
March		2 050	2 250	210	1 140	
April		1 400				
May						

The water constraint in Equation 6 demands that the crop water requirements based on area cultivated for the particular month should be less or equal to the total water quota available per month. This means that the irrigation water required for the two seasons should be less or equal to the water quota allocated on yearly basis as indicated in Equation 7. Stated differently, this means that the water required for each month should be less or equal to the available water quota per year (see Equation 8).

$$\sum_{i=1}^{6}\sum_{j=1}^{12} a_{ij} X_i \leq W_j \quad \text{.......................................}(6)$$

$$\sum_{j=1}^{12} W_j \leq WQ \quad \text{.......................................}(7)$$

$$\sum_{s=1}^{2} W_s \leq WQ \quad \text{.......................................}(8)$$

where:

s = 1,2 season

a_{ij} = per hectare irrigation water needs of crop i during month j

W_j = the quantity of water available during month j

W_s = the quantity of water used in each season

WQ = the total water quota available for irrigation during winter and summer

4.2.3 Non negativity restraint

The area planted to any crop should be greater than or equal to zero. This means that there will be no negative crop area.

$$X_i \geq 0 \quad \text{......(10)}$$

4.2.4 Linear Programming Matrix

The final matrix showing the objective function and the constraints for computer analysis is shown in Table 4.7. The matrix consists of the objective function, which is gross margin and linear constraints namely, available irrigable land, tractor power, labour hours and available irrigation water. The model makes provision for irrigation water left in one month to be used in the following month until all is used up. The upper limit denoted by X is used to indicate the maximum amount of a given resource or constraint available which vary with different farm groups.

Table 4.7: Linear Programming Matrix for optimising irrigation water resource use in the Ramah Canal at Vanderkloof Dam, 2001

	PRODUCTION ACTIVITIES						WATER CONSUMED IN MONTHS (M^3/MONTH)														
	Wt	Ml	Ln	Gn	Ct	Po	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May			
Objective function	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
OPTIMAL SOLUTION	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		RHS
Water requirement (m^3/ha)																					
June							-1												0	<=	X
July	630							-1											0	<=	X
August	1110								-1										0	<=	X
September	1170		1500							-1									0	<=	X
October	1540		2250	850	800	490					-1								0	<=	X
November	1510		2250	1640	1510	790						-1							0	<=	X
December		960	2250	1680	1200	990							-1						0	<=	X
January		1900	2250	1690	1790	1480								-1					0	<=	X
February		2060	2250	1740	2180	700									-1				0	<=	X
March		2050	2250	210	1140											-1			0	<=	X
April		1400															-1		0	<=	X
May																		-1	0	<=	X
Tractor power (hrs/ha)																					
January	0.00	1.00	5.33	0.00	0.50	0.32													0	<=	X
February	0.00	0.00	5.33	0.00	0.00	0.64													0	<=	X
March	0.00	0.00	5.33	0.00	0.00	0.32													0	<=	X
April	0.00	0.00	5.33	8.00	0.32	16.00													0	<=	X
May	0.00	0.00	0.00	17.60	0.00	0.00													0	<=	X
June	2.73	1.00	0.00	0.00	0.00	0.00													0	<=	X
July	0.67	0.53	0.00	0.53	0.53	0.53													0	<=	X
August	0.32	0.00	0.80	0.53	0.53	1.67													0	<=	X
September	0.00	0.00	5.33	2.20	2.20	0.53													0	<=	X
October	0.00	0.00	5.33	1.21	1.12	2.67													0	<=	X
November	0.00	0.00	5.33	0.00	1.00	1.32													0	<=	X
December	0.00	3.94	5.33	2.66	1.32	0.32													0	<=	X
Labour (hrs/ha)																					
January	0.00	1.00	5.86	0.00	8.00	0.64													0	<=	X
February	0.00	0.00	5.86	0.00	8.00	1.28													0	<=	X
March	0.00	0.00	5.86	0.00	8.00	0.64													0	<=	X
April	0.00	0.00	5.86	96.00	0.00	230													0	<=	X
May	0.00	0.00	0.00	80.00	8.00	0.00													0	<=	X
June	2.73	0.00	0.00	0.00	0.00	0.00													0	<=	X
July	2.68	1.06	0.00	0.53	0.53	0.53													0	<=	X
August	0.64	0.00	1.60	0.53	0.53	1.67													0	<=	X
September	0.00	0.00	5.86	2.20	2.20	0.53													0	<=	X
October	0.00	0.00	5.86	4.20	3.84	26.70													0	<=	X
November	0.00	0.00	5.86	0.00	1.00	1.64													0	<=	X
December	0.00	6.93	5.86	1.33	9.32	0.64													0	<=	X
Maximum water quota (m^3)							1	1	1	1	1	1	1	1	1	1	1	1	0	<=	X
Maximum land available (ha)	1	1	1	1	1	1													0	<=	X
Max Wheat	1																		0	<=	X
Max Maize		1																	0	<=	X
Max Lucerne			1																0	<=	X
Max Groundnuts				1															0	<=	X
Max Cotton					1														0	<=	X
Max Potatoes						1													0	<=	X

X = denotes the maximum amount of an input (resource) available

4.3 SENSITIVITY ANALYSIS

Pannell (1997) broadly defined sensitivity analysis as investigation of potential changes and errors and their impacts on conclusion to be drawn from a model. In this study the sensitivity analysis are carried out on water quota variations to find their impact on the optimal solutions.

To examine the economic consequences of decreasing irrigation water supply (water quota) to the farms, a parametric programming technique will be applied. First, the optimal solution for variable parameter XPARAM at 100 per cent (11 000 m^3) will be obtained. After this, a subsequent 25 per cent reduction from the original value will be made (Equation 11). Hence, optimal solution will be sought after 25 per cent, 50 per cent and 75 per cent (XPARDELT) reductions in the water quota as in equation 12, 13 and 14 respectively. The mathematical expression of this parameterisation on water quota is as follows:

$$\sum_{s=1}^{2} W_s \leq WQ_{100\%} \qquad \text{.......(11)}$$

$$\sum_{s=1}^{2} W_s \leq WQ_{75\%} \qquad \text{.......(12)}$$

$$\sum_{s=1}^{2} W_s \leq WQ_{50\%} \qquad \text{.......(13)}$$

$$\sum_{s=1}^{2} W_s \leq WQ_{25\%} \qquad \text{.......(14)}$$

where:

W_s	=	the quantity of water available per year (in two seasons).
$W_{s\ 100\%}$	=	maximum water quota allocation in a cropping year of two seasons
$W_{s\ 75\%}$	=	annual water quota allocation at 25 per cent reduction.
$W_{s\ 50\%}$	=	annual water quota allocation at 50 per cent reduction.
$W_{s\ 25\%}$	=	annual water quota allocation at 75 per cent reduction.

4.4 CONCLUSION

In this chapter the technical details of a linear programming model were discussed. Specifically, the chapter focused on:

- Developing a linear programming simulation model to optimally allocate irrigation water for farmers on Ramah Canal at Vanderkloof Dam.

- Describing and quantifying the variables of the model namely gross margin as the objective function and land, tractor power, labour and water as the constraints. Relevant mathematical equations that describe the relationships of the objective function and the constraints were developed and expressed.

- Describing the sensitivity analysis, which will be done to show the impact of water quota variations on optimal crop mix and optimal profit.

These results will be useful to farmers, extension service and decision makers in developing management strategies aimed at better use of water resources to achieve higher agricultural returns.

CHAPTER 5

EMPIRICAL RESULTS FROM THE LINEAR PROGRAMMING MODEL

5.1 INTRODUCTION

Scarcity of irrigation water is one of the major problems farmers are likely to face in future in the Orange River. A Linear Programming model was developed in the previous chapter to determine optimal allocation of irrigation water as input into production of various crops. Three farm groups were identified for the study. Group discussions were held with farmers representing each farm group to determine suitable crop combinations to simulate in LP for summer and winter seasons under unconstrained and constrained water supply regimes. The model used data on available land, water, water, labour and tractor requirements per crop, for different crops (maize, wheat, lucerne, cotton, groundnuts and potatoes) with the aim of maximising gross margin generated from those crops. Data employed into the model was obtained from enterprise budgets and from a structured questionnaire.

The results for the LP model for the three farm groups are presented in this chapter. The short run solution was obtained by LP model in order to get crop mix farmers can use to increase immediate profits. An upper limit was placed on all resources in accordance with the present availability per farm group. The analysis of the LP results is carried out in two stages. The first stage consists of the optimum combination of crop mix; the optimum allocation of resources; and optimal total gross margin. The seasonal MVPs for water were also derived for various crops. The MVPs determine how much a farmer can afford to pay for additional unit of water used in the production process. The second stage is the post-optimality analysis, whereby a sensitivity analysis was performed to study the effect of limitations on irrigation water on the optimal solution. Strategies farmers would use when irrigation water becomes limited in the short, medium and long run are also discussed in this chapter.

5.2 OPTIMUM ALLOCATION OF RESOURCES

5.2.1 Land

The optimal allocation of land is presented in Tables 5.1 to 5.3 for 75, 180 and 240 ha farm, respectively. In each farm group, there are five crop mixes, which farmers can choose from. Each crop mix consists of summer crops and one winter crop (wheat). In all farm groups, the last crop mix (Crop Mix 5) is a benchmark showing all irrigated land made available to maize production in summer and wheat in winter. Land utilisation for individual farm group is discussed below.

5.2.1.1 Land utilisation on 75 ha farm

Table 5.1: Optimum area allocated to different crop mixes in summer and winter seasons on 75 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

CROP MIX	SEASON	
	SUMMER	WINTER
1	60 ha maize, 15 ha lucerne (ML)	60 ha wheat (W)
2	60 ha maize, 15 ha potatoes (MP)	60 ha wheat (W)
3	60 ha maize, 15 ha groundnuts (MG)	60 ha wheat (W)
4	60 ha maize, 15 ha cotton (MC)	60 ha wheat (W)
5	75 ha maize (M benchmark)	75 ha wheat (W benchmark)

Table 5.1 shows crop mixes (Crop Mix 1, 2, 3, 4, and 5) that can be cultivated in summer and winter seasons on 75 ha farm. For the first four crop mixes, two summer crops and a winter crop can be produced whereas with the last crop mix, only maize can be produced in the summer season and wheat in winter. The results show that it is optimal to utilise fully all the available land during summer and winter seasons. For example in Summer Crop Mix 1 (ML), it is optimal to cultivate 60 ha of maize and 15 ha of lucerne in summer season and 60 ha of wheat in winter.

5.2.1.2 Land utilisation on 180 ha farm

Table 5.2: Optimum area allocated to different crop mixes in summer and winter seasons on 180 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

CROP MIX	SEASON	
	SUMMER	WINTER
1	120 ha maize, 30 ha potatoes, 30 ha cotton (MPC)	120 ha wheat (W)
2	120 ha maize, 30 ha Lucerne, 30 ha potatoes (MLP)	120 ha wheat (W)
3	102 ha maize, 30 ha Lucerne, 30 ha groundnuts (MLG)	120 ha wheat (W)
4	112 ha maize, 30 ha Lucerne, 30 ha cotton (MLC)	120 ha wheat (W)
5	180 ha maize (M benchmark)	180 ha wheat (W benchmark)

The optimal allocation of irrigated land on 180 ha farm is presented in Table 5.2. Three summer crops and one winter crop can be produced on 180 ha farm per crop mix for the first four crop mixes. It may be observed that for Crop Mix 1, 2 and 5, it is optimal to utilise all the available land in summer and winter season. With Summer Crop Mix 3 and 4, it is optimal to produce maize on 102 and 112 ha, respectively.

5.2.1.3 Land utilisation on 240 ha farm

Table 5. 3: Optimum area allocated to different crop mixes in summer and winter seasons on 240 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

CROP MIX	SEASON	
	SUMMER	WINTER
1	180 ha maize, 30 ha potatoes, 30 ha cotton (MPC)	180 ha wheat (W)
2	180 ha maize, 30 ha Lucerne, 30 ha potatoes (MLP)	180 ha wheat (W)
3	180 ha maize, 30 ha Lucerne, 30 ha groundnuts (MLG)	180 ha wheat (W)
4	180 ha maize, 30 ha Lucerne, 30 ha cotton (MLC)	180 ha wheat (W)
5	240 ha maize (M benchmark)	240 ha wheat (W benchmark)

Table 5.3 shows optimal allocation of irrigated land on 240 ha farm. Similar to 180 ha farm, three summer crop and one winter crop can be produced per crop mix for the first four crop mixes. The last crop mix consists of maize in summer season and wheat in winter crop. All the available land is fully utilised by the crop mixes. For example, in

Crop Mix 1 it is optimal to produce 180 ha of maize, 30 ha of potatoes and 30 ha of cotton in summer season and 180 ha of wheat in winter season.

5.2.2 Water requirements

The monthly optimal water requirement by different crop mixes on 75, 180 and 240 ha farms is given in Tables 5.4, 5.5 and 5.6, respectively. It can be seen that the peak water demand for summer crops is in the months of January to March mainly for flowering and seed formation. For winter crops, most of the water is demanded in October to November. Although lucerne is a perennial crop, it is assumed that in winter season very little water (sometimes none at all) is used to irrigate the crop since it is not actively growing (dormant). Consequently, the water allocated to lucerne is distributed among other crops in different months so that in May and June no crop is irrigated.

5.2.2.1 Water requirements on 75 ha farm

Table 5.4: Monthly water requirements (m^3) by different crop combinations on 75 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	ML	MP	MG	MC	M (benchmark)	W	W (benchmark)
June	0	0	0	0	0	0	0
July	0	0	0	0	0	37,800	47,250
August	0	0	0	0	0	66,600	83,250
September	22,500	0	0	0	0	70,200	87,750
October	33,750	7,350	12,750	12,000	0	92,400	115,500
November	33,750	11,850	24,600	22,650	0	90,600	113,250
December	91,350	72,450	82,800	75,600	72,000	0	0
January	147,750	136,200	139,350	140,850	142,500	0	0
February	157,350	134,100	149,700	156,300	154,500	0	0
March	156,750	123,000	126,150	140,100	153,750	0	0
April	84,000	84,000	84,000	84,000	105,000	0	0
May	0	0	0	0	0	0	0
TOTAL	**727,200**	**568,950**	**619,350**	**631,500**	**627,750**	**357,600**	**447,000**

The quantity of water demanded by different crop mixes on 75 ha is shown in Table 5.4. In summer season, Crop Mix 1 consisting of maize and lucerne (ML) requires the largest volume of water of 727 200 m^3 for the whole growing season. The second largest volume of 631 500 m^3 is required by Summer Crop Mix 4 made up of maize and cotton (MC). The lowest demand for irrigation water is observed in Summer Crop Mix 2, maize and potato (MP) mix, which requires 568 950 m^3. Maize and groundnuts (MG) crop combination (Summer Crop Mix 3) requires the second lowest volume of water 619 350 m^3 throughout the growing season. In winter season, wheat grown on 60 ha of irrigated land (W) requires a total of 357 600 m^3. When the whole irrigated land is allocated to wheat (W benchmark), 447 000 m^3 of irrigation water is required to irrigate the crop throughout its growing season.

5.2.2.2 *Water requirements on 180 ha farm*

Table 5.5: Monthly water requirements (m^3) by different crop combinations on 180 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	MCP	MLP	MLG	MLC	M (benchmark)	W	W (benchmark)
June	0	0	0	0	0	0	0
July	0	0	0	0	0	75,600	113,400
August	0	0	0	0	0	133,200	199,800
September	0	45,000	45,000	45,000	0	140,400	210,600
October	38,700	82,200	93,000	91,500	0	184,800	277,200
November	69,000	91,200	116,700	112,800	0	181,200	271,800
December	180,900	211,840	215,435	210,830	172,800	0	0
January	326,100	338,791	311,238	333,624	342,000	0	0
February	333,600	334,497	328,994	363,212	370,800	0	0
March	280,200	312,303	282,078	330,894	369,000	0	0
April	168,000	167,183	142,239	156,523	252,000	0	0
May	0	0	0	0	0	0	0
TOTAL	**1,396,500**	**1,583,014**	**1,534,684**	**1,644,383**	**1,506,600**	**715,200**	**1,072,800**

The optimal amount of water required by different crop mixes on 180 ha farm is presented in Table 5.5. Summer Crop Mix 4 of maize, lucerne and cotton (MLC) requires the largest total volume of 1 644 380 m^3 throughout the growing season. Second is Summer Crop Mix 2 including maize, lucerne and potatoes mix (MLP), which requires 1 583 010 m^3 of water. Summer Crop Mix 1 of maize, cotton and potatoes (MCP) requires the least volume of water of 1 396 500 m^3. The second lowest volume of water of 1 506 600 m^3 is required by maize benchmark (Summer Crop Mix 5). In winter 715 200 m^3 of water are needed to produce 120 ha of wheat. The Winter Crop Mix 5 (benchmark) requires 1 072 800 m^3 of irrigation water.

5.2.2.3 Water requirements on 240 ha farm

Table 5.6: Monthly water requirements (m^3) by different crop combinations on 240 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	MCP	MLP	MLG	MLC	M (benchmark)	W	W (benchmark)
June	0	0	0	0	0	0	0
July	0	0	0	0	0	113,400	151,200
August	0	0	0	0	0	199,800	266,400
September	0	45,000	45,000	45,000	0	210,600	280,800
October	38,700	82,200	93,000	91,500	0	277,200	369,600
November	69,000	91,200	116,700	112,800	0	271,800	362,400
December	238,500	270,000	290,700	276,300	230,400	0	0
January	440,100	453,900	460,200	463,200	456,000	0	0
February	457,200	459,300	490,500	503,700	494,400	0	0
March	403,200	436,500	442,800	470,700	492,000	0	0
April	252,000	252,000	252,000	252,000	336,000	0	0
May	0	0	0	0	0	0	0
TOTAL	**1,898,700**	**2,090,100**	**2,190,900**	**2,215,200**	**2,008,800**	**1,072,800**	**1,430,400**

Table 5.6 shows monthly water required by different crop mixes on 240 ha farm. Summer Crop Mix 4 consisting of MLC requires the highest quantity of 2 215 200 m^3. Summer Crop Mix 3 (MLG) requires the second highest quantity of water of 2 190 900 m^3. A crop combination of MCP (Summer Crop Mix 1), demands the lowest volume of water of 1 898 700 m^3. The second lowest volume of water of 2 008 800 m^3 is demanded by Summer Crop Mix 5 (M benchmark). In winter 180 ha of wheat as designated by W requires 1 072 800 m^3 of water and if the total irrigated land (240 ha) is allocated to wheat (W benchmark), 1 430 400 m^3 of water are required throughout the growing season of the crop.

5.2.3 Tractor power requirements

Tractor hours required by different farm crops are presented in Tables 5.7, 5.8 and 5.9 for 75, 180 and 240 ha, respectively. Summer crops demand a lot tractor power in December for land preparation and planting and also in April and May for harvesting. For example, Summer Crop Mix 3 (MG) requires 264 hours in May for harvesting and 276 tractor hours for land preparation and planting. Wheat (winter crop) requires most tractor power in June during land preparation and planting.

5.2.3.1 Tractor power requirements for a 75 ha farm

Table 5.7: Monthly tractor hours required by different crop combinations on 75 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	ML	MP	MG	MC	M (benchmark)	W	W (benchmark)
January	140	65	60	67	75	0	0
February	80	10	0	0	0	0	0
March	80	5	0	0	0	0	0
April	80	240	120	5	0	0	0
May	0	0	264	0	0	0	0
June	60	60	60	60	75	164	205
July	32	40	40	40	40	40	50
August	12	25	8	8	0	19	24
September	80	8	33	33	0	0	0
October	80	40	18	17	0	0	0
November	80	20	0	15	0	0	0
December	316	241	276	256	296	0	0
TOTAL	**1,040**	**753**	**879**	**501**	**485**	**223**	**279**

The tractor hour requirement by a 75 ha farm for production of different crop combinations is given in Table 5.7. Summer Crop Mix 1 consisting of maize and lucerne (ML) has the highest demand of tractors of 1 040 hours per year mainly because of lucerne, which has to be cut several times before it becomes dormant. The second highest demand for tractor power is observed in Summer Crop Mix 4 consisting of maize and groundnuts (MG) requires of 879 hours per throughout the growing season. In contrary, Summer Crop Mix 5 (M benchmark) demands the lowest tractor hours of 485 hours. The second lowest tractor power of 501 hours is demanded by

Summer Crop Mix 4 consisting of maize and cotton (MC). In winter, Winter Crop Mix 1 to 4 (W) requires 223 hours whereas wheat benchmark requires 279 hours per year.

5.2.3.2 Tractor power requirements for a 180 ha farm

Table 5.8 Monthly tractor hours required by different crop combinations on 180 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	MCP	MLP	MLG	MLC	M (benchmark)	W	W (benchmark)
January	145	289	261	287	180	0	0
February	19	179	160	160	0	0	0
March	10	170	160	160	0	0	0
April	490	640	400	170	0	0	0
May	0	0	528	0	0	0	0
June	120	119	102	112	180	491	328
July	95	79	70	75	95	121	80
August	66	74	40	40	0	58	38
September	82	176	226	226	0	0	0
October	114	240	196	194	0	0	0
November	70	200	160	190	0	0	0
December	522	640	640	640	709	0	0
TOTAL	**1,732**	**2,805**	**2,942**	**2,252**	**1,164**	**670**	**446**

In Table 5.8, Summer Crop Mix 3 (MLG) crop combination requires the highest amount of tractor hour of 2 942 hours throughout the growing season. Second highest is Summer Crop Mix 2 (MLP) with 2 805 hours. Summer Crop Mix 5 (M benchmark) demands the lowest tractor hours of 1 164 whereas Summer Crop Mix 1 has the second lowest demand of 1 732 hours per year. Peak demands for tractors are in December during land preparation and planting of summer crops and also in April to May during harvesting. In winter season, wheat (W) requires 446 hours when planted to 60 ha and 670 hours when full-irrigated area (W benchmark) is allocated to the crop.

5.2.3.3 Tractor power requirements for a 240 ha farm

Table 5.9 Monthly tractor hours required by different crop combinations on 240 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	MPC	MLP	MLG	MLC	M (benchmark)	W	W (benchmark)
January	205	349	340	355	240	0	0
February	19	179	160	160	0	0	0
March	10	170	160	160	0	0	0
April	490	640	400	170	0	0	0
May	0	0	528	0	0	0	0
June	180	180	180	180	240	491	655
July	127	111	111	111	127	121	161
August	66	74	40	40	0	58	77
September	82	176	226	226	0	0	0
October	114	240	196	194	0	0	0
November	70	200	160	190	0	0	0
December	758	879	949	909	946	0	0
TOTAL	**2,120**	**3,197**	**3,450**	**2,693**	**1,553**	**670**	**893**

Table 5.9 shows that Summer Crop Mix 3 consisting of maize, lucerne and groundnuts (MLG) the highest tractor hours of 3 450 hours. In the second position is Summer Crop Mix 2 made up of maize, lucerne and potatoes (MLP) with 3 197 hours. In the third position is Summer Crop Mix 4, consisting of maize, lucerne and cotton (MLC) with 2 693 hours and least is Maize (M benchmark) with 1 553 hours. In winter wheat (W) that goes with Summer Crop Mix 1 to 4, requires 670 hours for 120 ha or 893 hours per year when the full irrigated area (W benchmark) is planted to the crop.

5.2.4 Labour requirements

Labour hours required by different crop mixes are shown in Tables 5.10, 5.11 and 5.12 for 75, 180 and 240 ha farm group, respectively. Peak demand for labour is in December for land preparation and planting of summer crops and also for harvesting of wheat (winter crop). High demand for labour is also in April to May during harvesting of summer crops and planting of winter crops. During these two periods, casual labour is required to assist regular labour.

5.2.4.1 Labour requirements for a 75 ha farm

Table 5.10: Monthly labour hours required by different crop combinations on 75 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	ML	MP	MG	MC	M (benchmark)	W	W (benchmark)
January	148	70	60	180	75	0	0
February	88	19	0	120	0	0	0
March	88	10	0	120	0	0	0
April	88	3,450	1,440	0	0	0	0
May	0	0	1,200	120	0	0	0
June	60	60	60	60	75	164	205
July	64	72	72	72	80	161	201
August	24	25	8	8	40	38	48
September	88	8	33	33	0	0	0
October	88	401	63	58	0	0	0
November	88	25	0	15	0	0	0
December	504	425	436	556	520	0	0
TOTAL	**1,327**	**4,563**	**3,371**	**1,341**	**789**	**363**	**454**

The monthly labour hours required by different crop combinations on 75 ha farm are given in Table 5.10. In a Summer Crop Mix 2 consisting of potatoes and maize (MP), potatoes require about 3 450 hours which is an equivalent of 20 casual labourers in April for harvesting. As a result, the crop mix has the highest demand for labour of 4 563 hours throughout the growing season. In a Summer Crop Mix 3 consisting of maize and groundnuts (MG), groundnuts need 1 440 hours or seven casual labourers in April and 1 200 hours or six casual labourers in May also during harvesting. Subsequently, the crop mix has the second highest demands for labour of 3 371 hours per year. In the third position is Summer Crop Mix 4 of maize and cotton (MC) which requires a total of 1 341 hours per year. In December, an extra labourer is required to assist in land preparation, planting summer crops and to assist in harvesting wheat. Summer Crop Mix 5 (maize benchmark) compared to other summer crop mix has the least demand for labour, which is 789 hours throughout the growing season.

5.2.4.2 Labour requirements for a 180 ha farm

Table 5.11: Monthly labour hours required by different crop combinations on 180 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	MCP	MLP	MLG	MLC	M (benchmark)	W	W (benchmark)
January	379	314	277	528	180	0	0
February	278	214	176	416	0	0	0
March	259	195	176	416	0	0	0
April	6,900	7,076	3,056	176	0	0	0
May	240	0	2,400	240	0	0	0
June	120	119	102	112	180	491	328
July	159	142	124	134	191	482	322
August	66	98	64	64	0	115	77
September	82	192	242	242	0	0	0
October	916	977	302	291	0	0	0
November	79	225	176	206	0	0	0
December	1,130	1,023	920	1,230	1,247	0	0
TOTAL	**10,609**	**10,575**	**8,013**	**4,054**	**1,798**	**1,089**	**726**

In Table 5.11 labour is mostly required for potatoes production hence, Summer Crop Mix 1 including maize, cotton and potatoes (MCP) has the highest demand of 10 609 labour hours per year. Second is Summer Crop Mix 2, maize, lucerne and potatoes (MLP) with 10 575 hours. In the third position is Summer Crop Mix 3 (MLG) with 8 013 hours and fourth is Summer Crop Mix 4 comprising maize, lucerne and cotton (MLC) with 4 054 hours. Winter Crop Mix 5 comprising of wheat alone (W benchmark) has the least demand of 726 labour hours.

5.2.4.1 Labour requirements for a 240 ha farm

Table 5.12: Monthly labour hours required by different crop combinations on 240 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

MONTH	SUMMER					WINTER	
	MPC	MLP	MLG	MLC	M (benchmark)	W	W (benchmark)
January	439	375	356	596	240	0	0
February	278	214	176	416	0	0	0
March	259	195	176	416	0	0	0
April	6,900	7,076	3,056	176	0	0	0
May	240	0	2,400	240	0	0	0
June	180	180	180	180	240	491	655
July	223	207	207	207	254	482	643
August	66	98	64	64	0	115	154
September	82	192	242	242	0	0	0
October	916	977	302	291	0	0	0
November	79	225	176	206	0	0	0
December	1546	1,442	1,463	1,703	1663	0	0
TOTAL	**11,209**	**11,181**	**8,796**	**4,735**	**2,398**	**1,089**	**1,452**

Table 5.12 shows that the highest demand for labour is in April followed by May during harvesting of summer crops and planting of winter crops. The third highest demand for labour is in December for land preparation and planting of summer crops and also for harvesting wheat.

The next section shows how the above mentioned crop mixes respond to unconstrained and when irrigation water is limited.

5.3 OPTIMUM SOLUTION FOR SUMMER AND WINTER SEASONS UNDER UNCONSTRAINED IRRIGATION SUPPLY

Unconstrained amount of water required for each crop mix (combination) was determined by LP model, which took into account the gross margin per hectare (of each crop involved in the crop mix), constrained by individual crop's water requirements, total area allocated to each crop and the total water supply available. The LP results for different crop combinations are presented by means of tables and graphs with linear segments which indicate the sequence by which crops will be irrigated based upon their contribution in maximising cropping mix. Thus, a crop that generates the highest gross margin per unit of water would be irrigated first. In contrast, the crop with the least gross margin per unit of water applied would be the last to be irrigated. The optimal cropping mix at each water availability level is determined by the amount of gross margin each crop contributes subject to the amount of water applied and the number of hectares that could be irrigated, given a field level water supply. The results for a 75 ha farm are presented in Tables 5.13 to 5.18 and illustrated in Figures 5.1 to 5.6. Similar tables and figures for 180 ha and 240 ha are presented in Appendix D and E, respectively.

5.3.1 Optimal areas allocated and resulting gross margins for various crop mixes on 75 ha under unconstrained irrigation water supply

The results for five summer crop mix and a winter crop on 75 ha farm are discussed below.

5.3.1.1 Summer Crop Mix 1

Table 5.13 and Figure 5.1 show the results of maize and potatoes combination on 75 ha farm

Table 5.13: Optimal crop areas and resulting gross margin for a 75 ha irrigated farm under unconstrained water supply on the Ramah Canal at Vanderkloof Dam - Summer Crop Mix 1, 2001

	Area selected per crop (ha)		
Water applied (m^3)	Maize	Potatoes	Gross margin (R)
0		0	0
20,000		5	72,876
40,000		9	145,753
60,000		14	218,629
66,750		15	243,225
80,000	2	15	244,425
100,000	4	15	246,236
200,000	16	15	255,292
400,000	40	15	273,405
500,000	52	15	282,461
568,950	60	15	288,705

The first 66 750 m^3 of water available to the farm would be allocated to 15 ha of potatoes, which would in turn contribute a gross margin of R243 225. With irrigation water supply of more than 66 750 m^3, maize would enter cropping mix and 60 ha of maize would reach full irrigation with about 502 200 m^3 or (568 950 m^3 – 66 750 m^3) of water available to the farm. Maize would generate a gross margin of R45 480 that is, (R288 705-R243 225). The crop mix would require 568 950 m^3 of water and could generate a gross margin of R288 705.

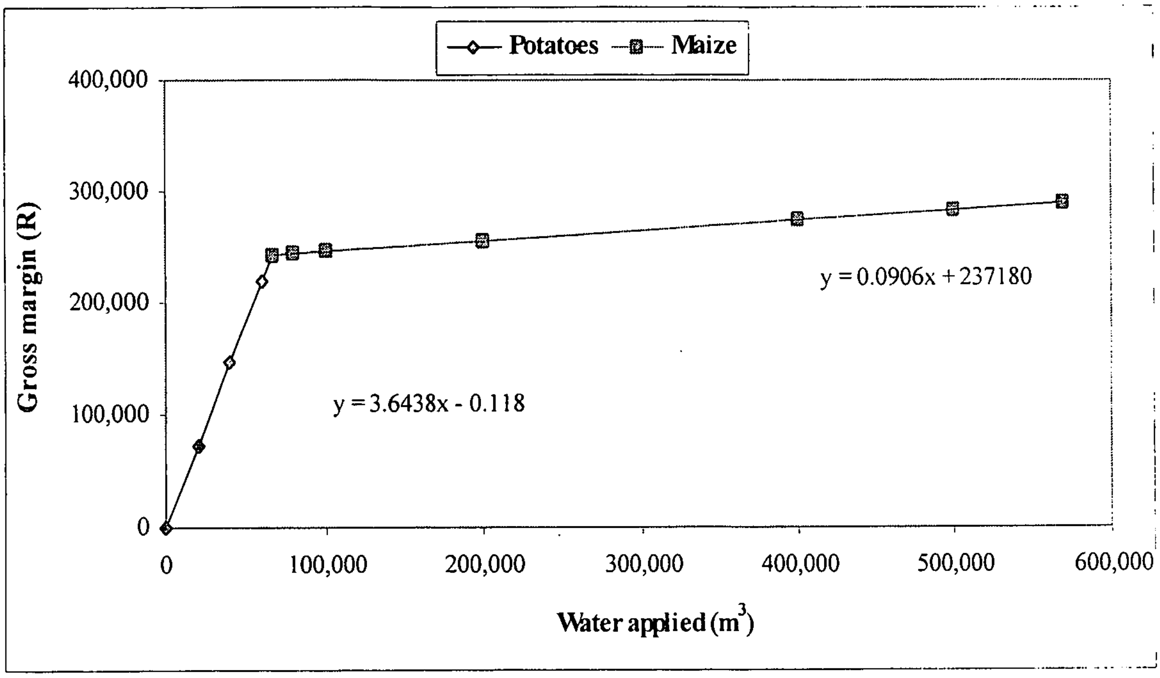

Figure 5.1: Gross margin as a function of water applied for potatoes and maize combination produced on the Ramah Canal at Vanderkloof Dam - Summer Crop Mix 1, 2001

In Figure 5.1, the relationship between water applied and gross margin for the two crops is presented by means of linear segments. The first linear segment is for potatoes whereas the second linear segment is for maize. The figure shows that potato attains high gross margin at lower units of water application than maize.

5.3.1.2 Summer Crop Mix 2

The results for Summer Crop Mix 2 under unconstrained irrigation water supply are indicated in Table 5.14 and Figure 5.2.

Table 5.14: Optimal crop areas and resulting gross margin for a 75 ha irrigated farm under unconstrained water supply on the Ramah Canal at Vanderkloof Dam - Summer Crop Mix 2, 2001

Water applied (m^3)	Area selected per crop (ha)		Gross margin (R)
	Maize	Lucerne	
0			0
50,000		3	9,067
100,000		7	18,133
150,000		10	27,200
200,000		13	36,267
225,000		15	40,800
250,000	3	15	43,064
300,000	9	15	47,592
400,000	21	15	56,680
500,000	33	15	65,704
600,000	45	15	74,761
700,000	57	15	83,817
727,200	60	15	86,280

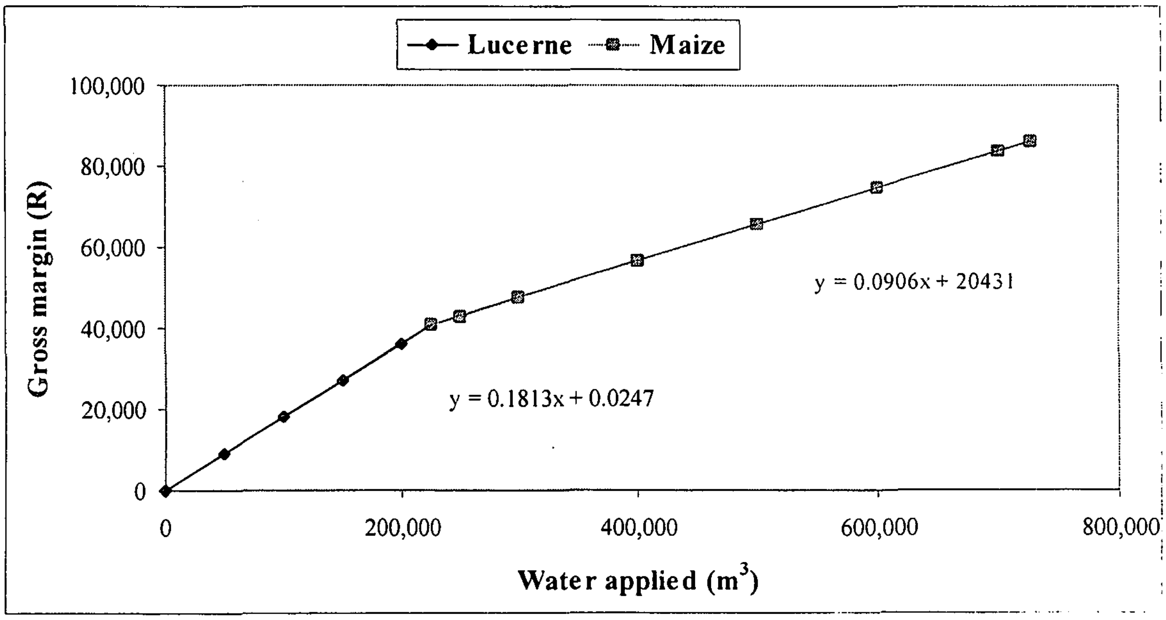

Figure 5.2: Gross margin as a function of water applied for lucerne and maize combination produced on the Ramah Canal at Vanderkloof Dam - Summer Crop Mix 2, 2001

In Table 5.14 and Figure 5.2 the first 225 000 m^3 of water would be applied to 15 ha of irrigated lucerne, which would contribute a gross margin of R40 800. The full area allocated to maize would be introduced to irrigation after lucerne and would require 502 000 m^3 (or 727 200 m^3 – 225 000 m^3) to generate a gross margin of R45 480 (R86 280 – R40 800). The crop mix would require 727 200 m^3 of water resulting in a gross margin of R86 280. In Figure 5.2, the relationship between gross margin and water applied is presented in linear segments for maize and lucerne. The first linear segment is for lucerne, which is introduced early at a low water level because of its high contribution to the total gross margin relative to that of maize. Maize is introduced to irrigation when the water demand of lucerne has been satisfied.

5.3.1.3 Summer Crop Mix 3

The optimum solution for maize and cotton under unconstrained water supply is presented in Table 5.15 and illustrated in Figure 5.3.

Table 5.15: Optimum crop area and resulting gross margin on 75 ha farm under unconstrained water supply on the Ramah Canal at Vanderkloof Dam - Summer Crop Mix 3, 2001

Water applied (m^3)	Area selected per crop (ha)		Gross margin (R)
	Maize	Cotton	
0		0	0
20,000		2	4,993
40,000		5	9,986
60,000		7	14,979
80,000		9	19,972
100,000		12	24,965
120,000		14	29,958
129,300		15	32,280
140,000	1	15	33,249
200,000	8	15	38,683
400,000	32	15	56,795
600,000	56	15	74,907
631,500	60	15	77,760

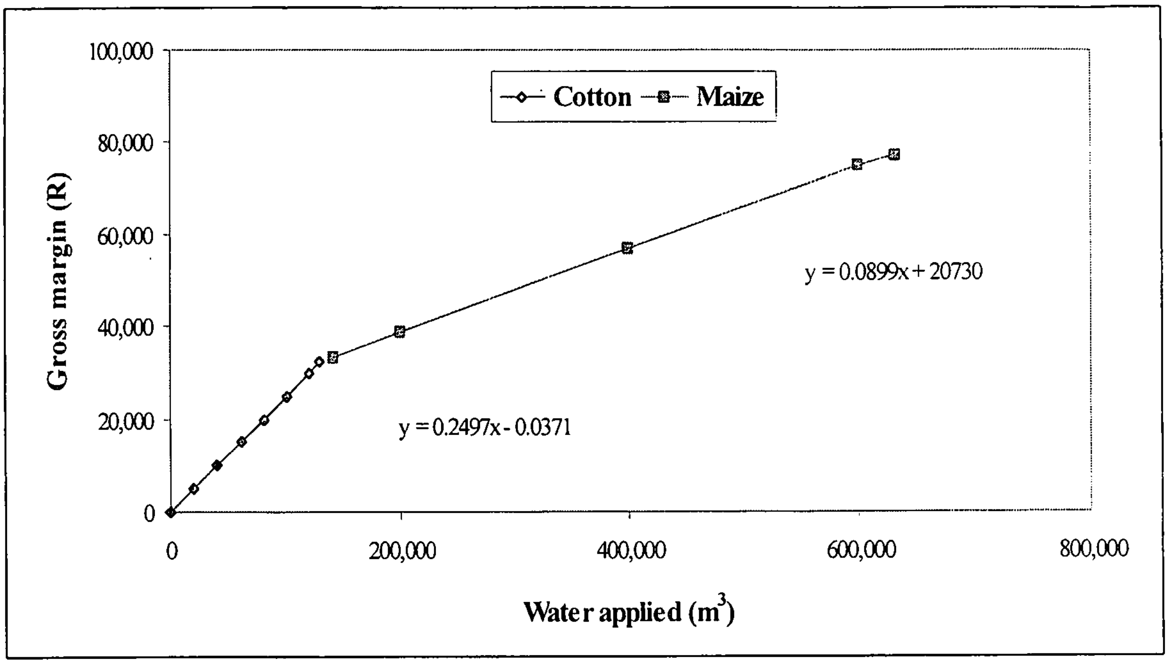

Figure 5.3: Gross margin as a function of water applied for cotton and maize combination produced on the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001

In a crop mixture of cotton and maize presented in Table 5.15 and Figure 5.3, the first 129 300 m^3 of irrigation water would be allocated to 15 ha of cotton, which in turn would contribute a gross margin of R32 280. As irrigation water becomes abundant, maize would enter crop mix at water availability level above 129 300 m^3. The full area allocated to the crop (maize) would reach full irrigation with about 502 200 m^3 of water and gross margin of R45 480 (R77 760 – R32 280) could be generated. The gross margin of R77 760 could be realised with 631 500 m^3 of water available to the farm.

5.3.1.4 Summer Crop Mix 4

Table 5.16 and Figure 5.4 show the results for maize and groundnuts combination on a 75 ha farm.

Table 5.16: **Optimal crop areas and resulting gross margin for a 75 ha farm under unconstrained water supply farm on the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 4, 2001**

Water applied (m^3)	Area selected per crop (ha)		Gross margin (R)
	Maize	Groundnuts	
0		0	0
20,000		3	9,639
40,000		5	15,278
60,000		8	22,917
80,000		10	30,556
100,000		13	38,195
117,150		15	44,745
120,000	0	15	45,003
200,000	10	15	52,248
300,000	22	15	61,304
400,000	34	15	70,360
600,000	58	15	88,473
619,350	60	15	90,225

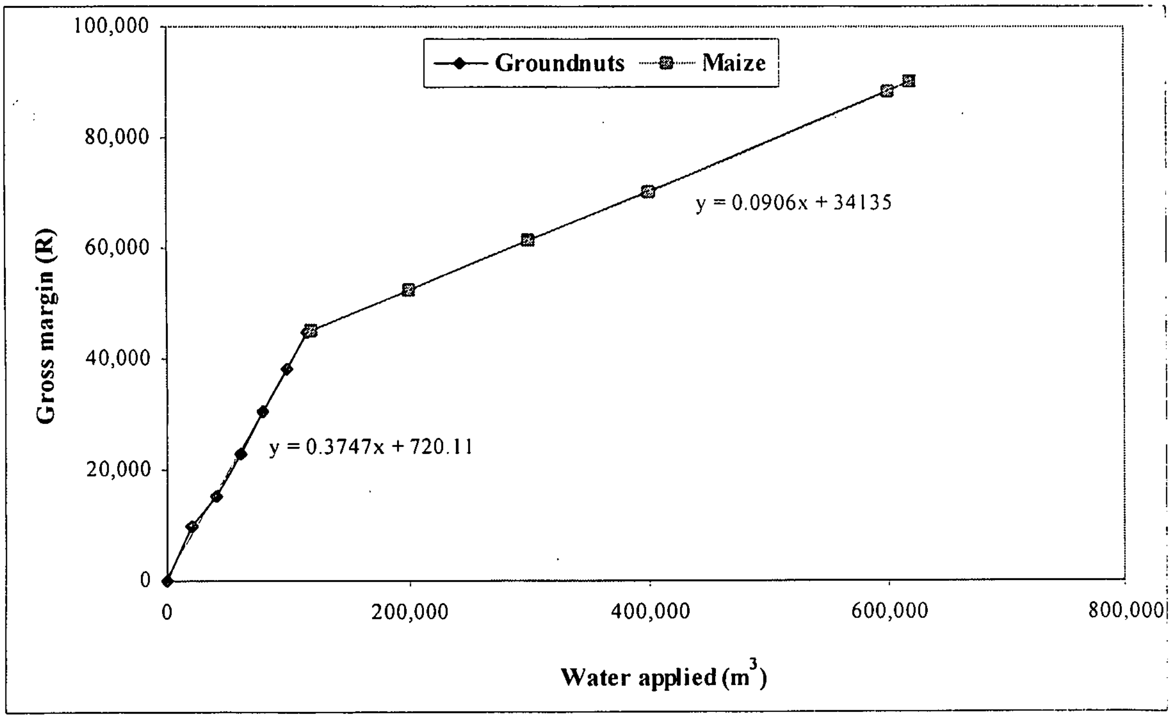

Figure 5.4: **Gross margin as a function of water applied for groundnuts and maize combination produced on the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 4, 2001**

The first 117 150 m^3 of irrigation water available to the farm would be allocated to 15 ha of groundnuts and a gross margin of R44 745 would be realised. Beyond 117 150 m^3, maize would be introduced to irrigation and 60 ha of the crop would require 502 200 m^3 (or 619 350 m^3 – 117 150 m^3) of irrigation water. A gross margin of R44 480 (that is, R90 225 – R44 757) would be realised from maize production. The crop mix would require a total of 619 350 m^3 of water and with that, a gross margin of R90 225 could be generated. For this crop combination, groundnuts are selected first because of their relative profitability.

5.3.1.5 Summer Crop Mix 5

Table 5.17 and Figure 5.5 show the response of maize (benchmark) to unconstrained irrigation water supply.

Table 5.17: Optimal crop areas and resulting gross margin for a 75 ha farm under unconstrained water supply farm on the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 5, 2001

Water applied (m^3)	Area selected (ha)	Gross Margin (R)
0		0
100,000	12	9,056
200,000	24	18,112
300,000	36	27,168
400,000	48	36,225
500,000	60	45,281
600,000	72	54,337
627,750	75	56,850

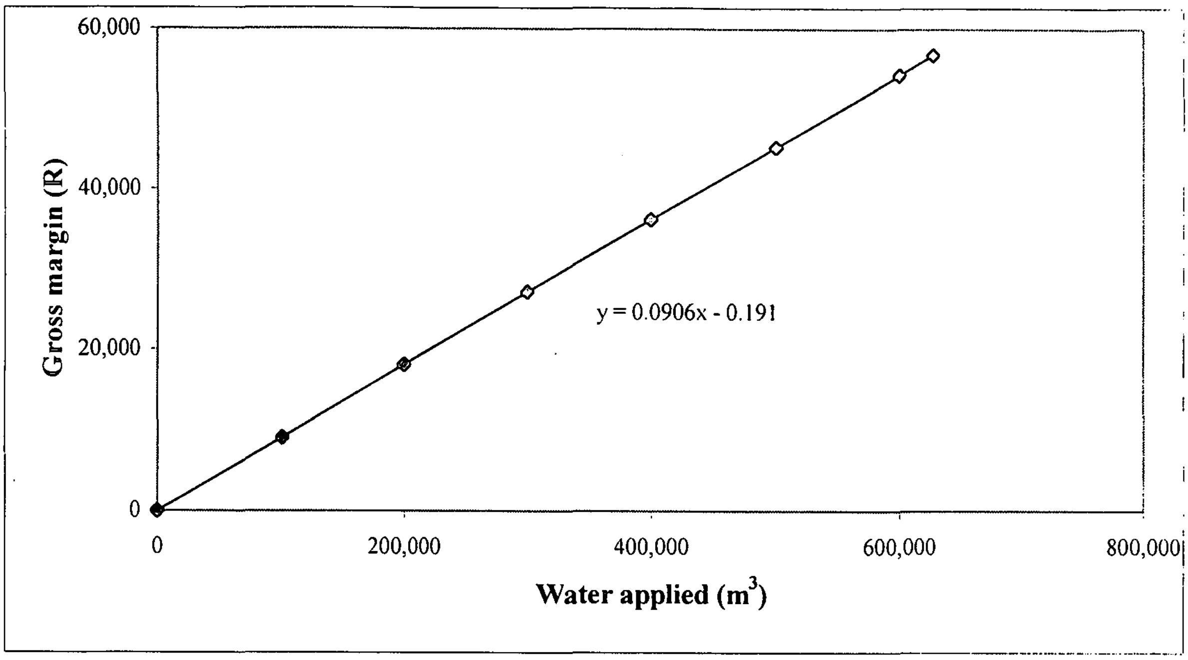

Figure 5.5: Gross margin as a function of water applied for maize produced on the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 5, 2001

The full area allocated to maize would require 627 720 m^3 of water and would in turn generate a gross margin of R56 850 as seen in Table 5.17 and Figure 5.5.

5.3.1.6 Winter Crop Mix 1-4

For winter season, wheat is the only crop considered and the results for the crop are presented in Table 5.18 and illustrated in Figure 5.6.

Table 5.18: Optimal crop areas and resulting gross margin for a 75 ha farm under unconstrained water supply on the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 1 – 4, 2001

Water applied (m^3)	Area (ha)	Gross Margin (R)
0	0	0
100,000	17	38,725
200,000	34	77,450
300,000	50	116,175
357,600	60	138,480

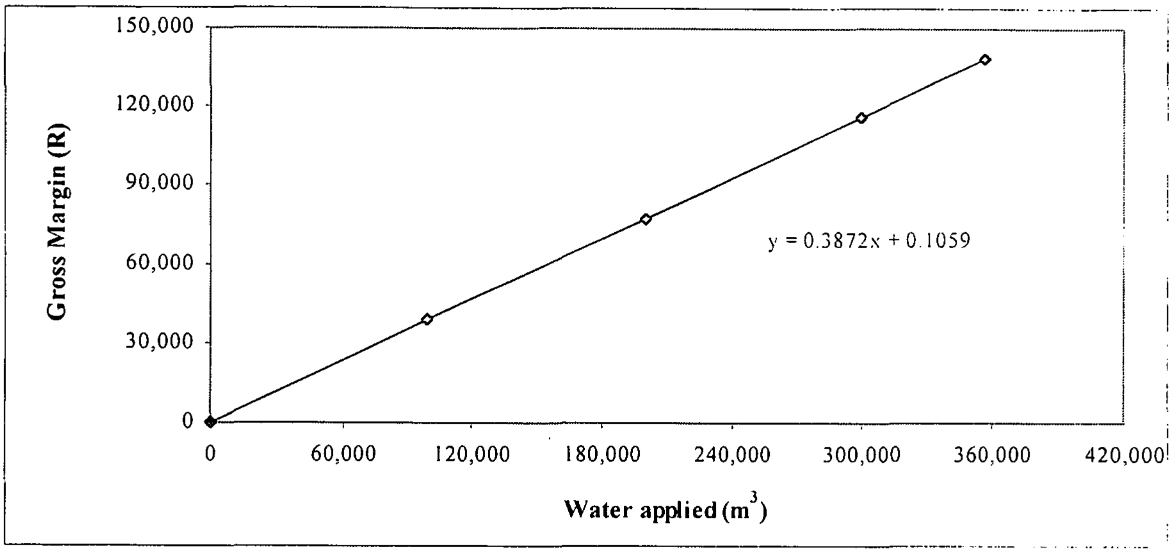

Figure 5.6: Gross margin as a function of water applied for wheat produced on the Ramah Canal at Vanderkloof Dam– Winter Crop Mix 1-4, 2001

The crop would require 357 600 m^3 of irrigation water to generate a gross margin of R138 480 (see Table 5.18 and Figure 5.6).

5.3.1.7 Winter Crop (benchmark)

Table 5.19: Optimal crop areas and resulting gross margin for a 75 ha farm under unconstrained water supply on the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 5, 2001

Water applied (m^3)	Area (ha)	Gross Margin (R)
0	0	0
100,000	17	38,725
200,000	34	77,450
300,000	50	116,175
357,600	60	138,480
447,000	75	173,100

The relationship between gross margin as a function of water applied for wheat produced on the total irrigable area (W benchmark) is presented in Table 5.19. The crop would demand 447 000 m^3 of irrigation water and could contribute a gross margin of R173 100.

5.3.2 Annual gross margin and water demands for various crop mixes on 75 ha farm

As mentioned earlier, farmers indicated that they would like to produce three crops per two growing seasons that is, two summer crops and a winter crop. Table 5.20 shows the annual gross margin a farmer can generate for pursuing any of the crop mixes that is, Crop mix 1 to 5 above. Table 5.21 shows the annual quantity of water that each crop mix would require per year or for two growing seasons, summer and winter season.

Table 5.20: Total gross margin for crop mixes generated from summer and winter seasons on 75 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

Crop Mix	Gross margin (R)		
	Summer	Winter	Total
1	288 705	138 480	427 185
2	86 280	138 480	224 760
3	77 160	138 480	215 640
4	90 225	138 480	228 705
5	56 850	173 100	229 950

Table 5.20 shows that Crop Mix 1 would generate the highest gross margin of R215 640. The lowest and the second lowest gross margin of R215 640 and 224 760 are obtained from Crop Mix 3 and Crop Mix 2 respectively. When comparing Crop Mix 5 (benchmark) with other crop mixes, the crop mix generates the lowest gross margin of R56 850 in summer whereas in winter season, the highest gross margin of R173 100 could be realised. This is because in winter season Winter Crop Mix 5 has an advantage of extra 15 ha compared to Winter Crop Mix 1 – 4 whereby wheat is rotated with maize on 60 ha of irrigated land.

Table 5.21: Total amount of irrigation water required by alternative crop mix for winter and summer seasons on 75 ha farm at the Ramah Canal Vanderkloof Dam, 2001

Crop Mix	Water applied (m^3)		
	Summer	Winter	Total
1	568 950	357 600	926 550
2	727 200	357 600	1 084 800
3	631 500	357 600	989 100
4	619 350	357 600	976 950
5	627 750	447 000	1 074 750

In Table 5.21, Crop Mix 2 and Crop Mix 5 require the largest and the second largest volume of water, respectively. Crop Mix 1 and Crop Mix 4 require the lowest and the second lowest volume of water respectively.

A farmer pursuing Crop Mix 1 consisting of maize, potatoes and wheat will require the lowest volume of 926 550 m^3 of water (Table 5.21) to generate the gross margin of R427 185 (Table 5.20), which is the highest gross margin compared to that generated by other crop mixes. In contrast, a farmer pursuing Crop Mix 2 will demand the highest quantity of the water of 1 084 800 m^3 while generating the second lowest gross margin of R224 760. With Crop Mix 5, a farmer would require 1 074 750 m^3, the second largest volume of water to obtain the second highest gross margin of R229 950. These results form the basis by which farmers can select the crop mixtures in the short-run based on resources that are most limiting in the farm.

5.3.3 Optimal areas and resulting gross margins for 180 ha farm under unconstrained irrigation supply

Appendix Tables D1 to D6 show optimal crop areas and corresponding gross margins for various crop mixes that can be produced on 180 ha farm.

5.3.3.1 Summer Crop Mix 1

In Table D1, the first 133 500 m^3 of water would be allocated to potatoes and these correspond to a gross margin of R486 450, which can be obtained with this water allocation. Next crop to be irrigated would be cotton at water availability level between 133 500 m^3 and 392 000 m^3, which is 258 500 m^3 and a gross margin of R63 560 (that is, R551 010 - R486 450) could be realised from 30 ha of cotton. Last crop to be irrigated would be maize. The full area allocated to maize would demand water quantity between 1 396 500 and 392 000 m^3, which is 1 004 500 m^3 of water. A gross margin of R90 960 (or R641 970 – R551 010) could be anticipated from 60 ha of maize. The crop mixture would demand 1 396 500 m^3 to generate a gross margin of R641 970 (Table D1 and Figure D1).

5.3.3.2 Summer Crop Mix 2

In Table D2, potato would be the first crop introduced into irrigation. The first 133 500 m^3 of irrigation water would be allocated to potatoes and the respective gross margin that could be obtained is R486 450. At water availability level between 584 000 m^3 and 133 500 m^3 amounting to a total demand of 450 500 m^3 lucerne would be introduced into irrigation and the corresponding gross margin of 99 600 m^3 (that is, R568 050 – R486 450) would be obtained. At water availability level of 584 000 m^3, maize would be considered for irrigation. The total area allocated to maize would require 1 004 500 m^3 (or 1 588 500 m^3-584 000 m^3) of water to generate a gross margin of R90 960 (or R659 010 – R568 050). The crop mix would demand 1 587 900 m^3 of water and would return a gross margin of R659 010 (Table D2 and Figure D2).

5.3.3.3 Summer Crop Mix 3

Table D3 and Figure D3 show the results for Summer Crop Mix 3 on 180 ha farm. Under Summer Crop Mix 3, it is optimal to produce 102 ha of maize, 30 ha of lucerne and 30 ha of groundnuts. The 30 ha of groundnuts would be irrigated first. Next would be 30 ha of lucerne and last will be 180 ha of maize. The crop mix would demand 1 534 684 m^3 of water and with this, a gross margin of R248 102 would be realised.

5.3.3.4 Summer Crop Mix 4

Table D4 and Figure D4 show Summer Crop Mix 4 for a 180 ha farm. Under this crop mix, it is optimal to produce 112 ha of maize, 30 ha of lucerne and 30 ha of cotton. Cotton would be irrigated first, followed by lucerne. As irrigation water becomes abundant, maize would be considered for irrigation. The crop mix would require 1 644 383 m^3 of irrigation water and the gross margin of R230 906 could be obtained.

5.3.3.5 Summer Crop Mix 5

The full area allocated to maize (180 ha) would demand 1 506 600 m^3 of water and would in turn give a gross margin of R136 000 (Table D5 and Figure D5).

5.3.3.6 Winter Crop mix 1 - 4

Wheat is the only crop considered in winter season. The crop (in Crop Mix 1-4) would demand 715 200 m^3 of water and in return a gross margin of R276 960 could be obtained (Table D6 and Figure D6).

5.3.3.7 Winter Crop (benchmark)

With wheat benchmark (Crop Mix 5), a total of 1 072 800 m^3 of water would be demanded and a gross margin of R415 400 could be obtained (Table D7 and Figure D7).

5.3.4 Annual gross margin and water demands for various crop mixes on 180 ha farm

Table 5.22 shows the total amount of gross margin that can be obtained from each crop mix whereas Table 5.23 shows the amount of water each crop mix would require on 180 ha farm.

Table 5.22: Total gross margin for crop mixes generated from summer and winter seasons on 180 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

Crop Mix	Gross margin (R)		
	Summer	Winter	Total
1	641 970	276 960	918 930
2	659 010	276 960	935 970
3	248 102	276 960	525 062
4	230 906	276 960	507 866
5	136 440	415 440	651 880

In Table 5.22, Crop Mix 2 and Crop Mix 1 generate the highest and the second highest amount of gross margin of R935 970 and 918 930, respectively. Crop Mix 4 and 3 generate the lowest and the second lowest gross margins of R507 866 and R525 062 respectively. While comparing Crop Mix 5 (benchmark) with other crop mixes, the crop mix has the lowest gross margin of R136 440 in summer season. Since in winter 60 additional hectares of land can be cultivated over and above 120 ha of land allocated to other crop mixes, the highest gross margin of R415 440 can be obtained, making Crop Mix 5 the third best crop mix in terms of gross margin that could be generated.

Table 5.23: Total amount of irrigation water demanded by various crop mixes for winter and summer seasons on 180 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

Crop Mix	Water application (m^3)		
	Summer	Winter	Total
1	1 396 500	715 200	2 111 700
2	1 587 900	715 200	2 303 100
3	1 534 684	715 200	2 249 884
4	1 644 383	715 200	2 359 583
5	1 506 600	1 072 800	2 579 400

The Crop Mix 5 (benchmark) demands the highest quantity of water of 2 579 400 m^3 whereas Crop Mix 1 demands the lowest quantity of water of 2 111 700 m^3.

Farmers can choose from any of the five above-mentioned crop mixes depending on their needs. For example, if a farmer chooses Crop Mix 1 made up of 120 ha maize, 30 ha cotton, 30 ha potatoes and 120 ha wheat, he will require a total of 2 111 700 m^3 of irrigation water and this will give him a gross margin of R918 930 in return. When the benchmark (Crop Mix 5) is compared to other alternative crop mixes, it requires the highest quantity of irrigation water (2 579 400 m^3) but generates the third highest gross margin of R651 880 after Crop Mix 1 and 2.

5.3.5 Optimal crop areas and resulting gross margins for 240 ha farm under unconstrained irrigation supply

The results for this farm group are attached in Appendix E in the form of tables and figures and are discussed below.

5.3.5.1 Summer Crop Mix 1

The response of gross margin to water applied for maize, cotton and potatoes crop combination on 240 ha is shown in Table E1 and presented by means of linear segments for each crop in Figure El (see Appendix E). The crop combination demands 1 898 700 m^3 of irrigation water to generate a gross margin of R687 450.

5.3.5.2 Summer Crop Mix 2

Table E2 and Figure E2 show gross margin as a function of water supplied for a crop combination consisting of maize, lucerne and potatoes. Potatoes would be irrigated first, followed by lucerne and last crop to be irrigated would be maize. The crop combination would demand 2 090 100 m^3 of irrigation water and can produce a gross margin of R704 490.

5.3.5.3 Summer Crop Mix 3

The response of maize, lucerne and groundnuts crop combination is reflected in Table E3 and Figure E3. Groundnuts are considered first for irrigation. Lucerne is irrigated next and last is maize. The crop combination can produce a gross margin of R307 530 with 2 190 900 m^3 of irrigation water.

5.3.5.4 Summer Crop Mix 4

The results for maize, lucerne and cotton crop combination are indicated in Table E4 and illustrated by means of linear segments for each crop in Figure E4. For this crop combination, cotton is regarded first for irrigation. Next is lucerne and lastly maize. The crop combination can generate R282 600 with 2 215 200 m^3 of irrigation water.

5.3.5.5 Summer Crop Mix 5

A full irrigated area allocated to maize would require a total of 2 008 800 m^3 of irrigation water to return a gross margin of R181 920.

5.3.5.6 *Winter Crop Mix 1 - 4*

For Crop Mixes 1-4, 180 ha of irrigated land would be cultivated to wheat. The crop demands 1 072 800 m^3 to generate R415 440 as gross margin (Table E6 and Figure E6).

5.3.5.7 *Winter Crop (benchmark)*

When the whole irrigated area (240 ha) is allocated to wheat in winter (Crop Mix 5), the gross margin of R553 920 could be obtained with 1 430 400 m^3 of water (Table E7 and Figure E7).

5.3.6 Annual gross margin and water demands for various crop mixes on 240 ha farm

The five crop mixes are compared to one another in terms of gross margin (Table 5.24) generated and quantity of water (Table 5.25) required by each.

Table 5.24: Total gross margin for crop mixes generated from summer and winter seasons on 240 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

Crop Mix	Gross margin (R)		
	Summer	Winter	Total
1	687 450	415 440	1 102 890
2	704 490	415 440	1 119 930
3	307 530	415 440	722 970
4	282 600	415 440	698 040
5	181 920	553 920	735 840

Table 5.25: Total amount of irrigation water required by crop mixes for winter and summer seasons on 240 ha farm at the Ramah Canal, Vanderkloof Dam, 2001

Crop Mix	Water applied (m^3)		
	Summer	Winter	Total
1	1 898 700	1 072 800	2 971 500
2	2 090 100	1 072 800	3 162 900
3	2 190 900	1 072 800	3 263 700
4	2 215 200	1 072 800	3 288 000
5	2 008 800	1 430 400	3 439 200

Table 5.24 and 5.25 show gross margin and water applied, respectively for the five crop mixes on 240 ha farm. For example, a farmer pursuing Crop Mix 4 consisting of 180 ha maize, 30 ha lucerne, 30 ha cotton and 180 ha wheat can generate a gross margin of R698 040 with 3 288 000 m^3 of irrigation water. When comparing the benchmark (Crop Mix 5) with other crop mixes, it is seen that it generates the lowest gross margin of R181 200 in summer. But since in winter, Crop Mix 5 (Winter benchmark) has an advantage of 60 ha of wheat over other winter crop mixes (Winter Crop Mix 1-4), it generates the highest amount of gross margin during that season. The yearly gross margin of R735 840 (the third highest gross margin) can be expected from both summer and winter benchmarks. Furthermore, the benchmark demands the largest volume of water of 3 439 200 m^3 for both summer and winter seasons. A total gross margin of R1 102 890 and R1 119 930 can be obtained from Crop Mix 1 and 2, respectively.

The gross margin as a function of water applied (Total Value Product function) presented as linear segments were used to determine seasonal MVP for water applied or water delivered to the farm. A linear trend line was fitted to each TVP function representing each crop. By taking the first derivative of the trend line the MVP for water for individual crops in a crop mix crops were determined. The MVPs for crop are discussed below.

5.4 MARGINAL VALUE PRODUCT FOR WATER FOR CROPS PRODUCED ON DIFFERENT FARM GROUPS

Table 5.26 shows the MVP for water derived from various crops involved in the study. The MVP for water represents what farmers would afford to pay for additional unit of water used to produce the crops.

Table 5.26: Marginal Value Product generated from Linear Programming model for crops produced under different water allocations on the Ramah Canal at Vanderkloof Dam, 2001

CROPS	SEASONAL MVP (R/m^3)
Maize	0.09
Lucerne	0.18
Cotton	0.25
Groundnuts	0.38
Wheat	0.39
Potatoes	3.64

Potatoes have the highest MVP of R3.64 per cubic meter of water. This means that, a farmer producing potatoes can afford to pay R3.64 for an additional cubic meter of water. Wheat has the second highest MVP of R0.39 per cubic meter of water. The MVPs' for other crops in decreasing order are R0.38, R0.25, R0.18 and R0.09 per cubic meter of water for groundnuts, cotton, lucerne and maize, respectively.

The MVP for water for individual crops is crop specific and does not change with different water availability levels. Moreover, the MVP for water forms the basis by which LP model selects the crops for irrigation given a crop mix. Thus, LP selects first crops with the highest MVP for water. This implies that such crops would be the first choice for irrigation whereas those with the lowest MVP for water would be the last choice. In summer season for example, LP would select potatoes first for irrigation. Potatoes would be followed by groundnuts, cotton, lucerne and lastly maize. In a crop mixture of cotton and maize on 75 ha farm, cotton is considered first for irrigation and maize last because of its low profitability relative to that of cotton.

Although maize generates the lowest MVP for water, it occupies more than 70 per cent of irrigated area in the Ramah Canal. The reasons why maize receives this much proportion of farm land can be stated as follows:

- Maize is a staple food in the country and can be sold readily.

- Machinery used in most farms is more amenable to maize production than any other summer crop.

- Maize and wheat require almost the same implements for their production, hence making the management of these crops relatively easy compared with crops such as potatoes, which requires a completely different set of implements throughout the production period.

- Because of the susceptibility of potatoes to scab and radical price fluctuations (R3 to R20 per 10 kg bag of potatoes) in the market, the maximum area that can be cultivated to the crop is 30 ha while the minimum is 15 ha.

- The microclimate is also a variable that contributes to specific production practices in the Ramah Canal area. For example, the cold weather in some parts of the Ramah Canal inhibits growth and performance of cotton in the area. Therefore, a minimum area that can be cultivated to the crop as suggested by farmers in the area is 30 ha whereas the maximum is 60 ha.

The full irrigation required by different crop mixes in different farm groups was reduced by different margins to determine how crops would behave to limited irrigation water supply condition. It is assumed that crops with the least MVP for water would leave optimum solution first under this condition (reduced irrigation water supply). The results for various crop mixes in different farm groups are discussed next for limited irrigation water supply.

5.5 POST OPTIMALITY ANALYSIS

In the previous section, the optimal resource utilisation, optimal crop enterprise combination and total gross margin for different crop mixes were analysed under unconstrained irrigation water availability. In this section, the sensitivity of the solutions with respect to limitations on irrigation water availability will be analysed.

Four hypothetical water allocations were studied for each crop mix to determine the implications of reduced water supplies. Water and land resources were allocated using a parametric linear programming model. The model was run at 100 per cent, 75 per cent, 50 per cent and 25 per cent of the total water available, subject to a given set of constraints. The results for different farm groups are discussed below.

5.5.1 Optimum solution of water for summer season under limited irrigation supply – 75 ha farm

The optimal crop mixes for a 75 ha farm under limited irrigation water supply are shown in Table 5.27 to 5.33. Similar results for 180 and 240 ha are presented Appendix F and G, respectively.

5.5.1.1 Summer Crop Mix 1

Table 5.27: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 1, 2001

Water availability Level	Total water available (m^3)	Area selected per crop (ha)		Gross margin (R)
		M	P	
100%	568,950	60	15	288,705
75%	426,713	43	15	275,824
50%	284,475	26	15	262,943
25%	142,238	9	15	250,061

Table 5.27 shows optimal crop combination of maize and potatoes resulting from different irrigation water limitations. The area under maize is reduced from 60 ha at

100 per cent water availability level to 43, 26 and 9 ha at 75, 50 and 25 per cent water availability levels respectively. With regard to potatoes, the full area allocated to the crop does not change even at reduced water availability levels because the crop enjoys the highest profitability level. The results further show that during summer season, the total area for cultivation of maize and potatoes is reduced to 58, 41 and 24 ha meaning that a total area of 17, 34 and 51 ha will be left unused with 75, 50 and 25 per cent water availability levels. The gross margin of R288 705, R275 824, R262 943 and R250 061 would be obtained with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.1.2 Summer Crop Mix 2

Table 5.28: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 2, 2001

Water availability Level	Total water available (m^3)	Area selected per crop (ha)		Gross margin (R)
		M	L	
100%	727,200	60	15	86,280
75%	545,400	38	15	69,816
50%	363,600	17	15	53,352
25%	181,800	0	12	32,966

Table 5.28 reflects the response of maize and lucerne crop combination when water supply is reduced from 100 per cent to 75, 50 and 25 per cent. The farm water allocation would be 545 400 m^3, 363 600 m^3 and 181 800 m^3 if limited water allocation is 75, 50 and 25 per cent of the full water allocation (727 200 m^3). The results indicate that the area under maize is reduced from 60 ha at 100 per cent to 38 and 17 with 75 and 50 per cent water availability level, respectively. At 25 per cent water availability level, maize disappears from the optimal solution because it consumes a lot of water with respect to its gross margin. Lucerne on the other hand responds to the highest water reduction level of 75 per cent (or 25 per cent water availability level) whereby the area under the crop is reduced to 12 ha. The results show that during summer season, the total area of 22 ha, 43 ha and 60 ha can be left unused at 75, 50 and 25 per cent water availability level,

respectively. The total gross margin of R86 280, R69 816, R53 352 and R32 966 can be achieved with 100, 75, 50 and 25 per cent water availability level, respectively.

5.5.1.3 Summer Crop Mix 3

Table 5.29: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 3, 2001

Water availability Level	Total water available (m^3)	Area selected per crop (ha)		Gross margin (R)
		M	C	
100%	631,500	60	15	77,760
75%	473,625	41	15	63,463
50%	315,750	22	15	49,165
25%	157,875	3	15	34,868

Table 5.29 reflects the response of maize and cotton crop combination when available water supply is reduced from 100 per cent to 75, 50 and 25 per cent of full water allocation. The area allocated to cotton is the maximum imposed area for the crop and there is no change even at reduced water availability levels. The area under maize on the other hand is reduced from 60 ha at 100 per cent water availability level to 41, 22 and . ha at 75, 50 and 25 per cent water availability level, respectively. The gross margin of R77 760, R63 463, R49 165 and R34 868 can be achieved at 100, 75, 50 and 25 per cent water availability level, respectively.

5.5.1.4 Summer Crop Mix 4

Table 5.30: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam– Summer Crop Mix 4, 2001

Water availability Level	Total water available (m^3)	Area selected per crop (ha)		Gross margin (R)
		M	G	
100%	619,350	60	15	90,225
75%	464,513	42	15	76,203
50%	309,675	23	15	62,180
25%	154,838	5	15	48,158

In Table 5.30 the response of maize and groundnuts on reduced water availability level is presented. Maize is more sensitive to reduced water supply than groundnuts. This is shown by the area under the crop (maize), which decreases from 60 ha at 100 per cent water availability level to 42, 23 and 5 ha with 75, 50 and 25 per cent water availability level respectively. On the other hand, the maximum area allocated to groundnuts does not change regardless of the limitations in water supply imposed on the crop. The gross margin of R90 225, R76 203, R62 180 and R48 158 can generated with 100, 75, 50 and 25 per cent water availability level respectively. The total area allocated to the two summer crops (maize and groundnuts) can be reduced to 57, 38 and 20 ha meaning that 18, 37 and 55 ha of irrigated land will be left unused at 75, 50 and 25 per cent water availability level respectively.

5.5.1.5 Summer Crop Mix 5

Table 5.31: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply on the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 5, 2001

Water availability Level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	627,750	60	56 850
75%	470,813	45	42,638
50%	313,875	30	28,425
25%	156,937	15	14,213

Similar to Table 5.30, the area allocated to maize is reduced by the same margin as the water availability levels. Therefore, the full area allocated to maize is reduced from 60 ha at 100 per cent water availability level to 45, 30 and 15 ha at 75, 50 and 25 per cent water availability level respectively. The gross margin of R56 850, R42 638, R28 425 and R14 213 may be achieved with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.1.6 Winter Crop Mix 1 - 4

Table 5.32: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply on the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 1 - 4, 2001

Water availability Level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	357,600	60	138,480
75%	268,200	45	103,860
50%	178,800	30	69,240
25%	89,400	15	34,620

Table 5.32 shows the response of wheat when the available irrigation water is reduced. The area allocated to wheat and gross margin that can be generated from the crop are decreased by the same margin as the reduction in the available water supply. Hence, the area under wheat is reduced from 60 ha at 100 percent water availability level to 45, 30 and 15 ha at 75, 50 and 25 per cent water availability level respectively. The gross margin of R138 480, R103 860, R69 240 and R34 620 may be achieved at 100, 75, 50 and 25 per cent water availability level respectively.

5.5.1.7 Winter Crop Mix 5

Table 5.33: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply on the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 5, 2001

Water availability level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	447,000	75	173,100
75%	335,250	56	129,825
50%	223,500	38	86,550
25%	111,750	19	43,275

Table 5.33 shows the optimal solution under limited water supply when the full available irrigated area (75 ha) is allocated to wheat in winter season. The area allocated to wheat is reduced from 75 ha at 100 per cent water availability level to 56, 38 and 19 ha with 75, 50 and 25 ha water availability level respectively. The gross margin of R173 100, R129 825, R86 550 and R43 275 will be obtained with 100, 75, 50 and 25 per cent water availability level respectively.

The last two tables for 75 ha farm show how maize and wheat will respond to water reductions when the whole irrigated area is allocated to the crops in summer and winter seasons respectively.

5.5.2 Optimum solution of water for summer season under limited irrigation water supply – 180 ha farm

5.5.2.1 Summer Crop Mix 1

Table F1 shows the optimal crop mix of maize, cotton and potatoes resulting from different irrigation water limitations. From the table, the area under maize is reduced from 120 at 100 per cent water availability level to 78 and 37 ha at 75 and 50 per cent water availability level. At 25 percent water availability level, maize disappears from the optimal solution. Cotton responds to the lowest water availability level of 25 per cent whereby its area is reduced to 25 ha. Potatoes are not affected by any reductions in water supply, hence the area allocated to the crop remains constant throughout. The gross margin of R641 970, R610 353, R578 735 and R540 281 are realised with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.2.2 Summer Crop Mix 2

Table F2 shows the response of maize, lucerne and potatoes at reduced water availability levels. The area under maize is reduced from 120 ha at 100 per cent water availability level to 73, 25 and 18 ha at 75, 50 and 25 per cent water availability level respectively. Lucerne responds to the lowest water availability level of 25 per cent whereby its area is reduced to 25 ha. The area under potatoes remains unchanged regardless of limitations imposed on available water required to irrigate the crop. The gross margin of R659 010, R623 059, R587 109 and R534 227 can be obtained with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.2.3 Summer Crop Mix 3

In Table F3 the response of maize, lucerne and groundnuts to reduced water supply is indicated. In this case 120, 56, 10 and 0 ha of maize can be optimally produced with 100, 75, 50 and 25 per cent water availability level respectively. Lucerne is only affected by 25 per cent reduction in water supply whereby its area is reduced to 10 ha. The area under groundnuts is not affected by any reductions in water supply. The gross margin of R248 102, R213 356, R178 910 and R116 576 can be generated with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.2.4 Summer Crop Mix 4

Table F4 shows the response of maize, lucerne and cotton to limited irrigation water supply. Maize is the only crop affected by reductions in water supply. The area under the crop is reduced from 120 ha at 100 per water availability level to 63, 14 and 10 ha with 75, 50 and 25 per cent water availability level (Table F4). The crop mix can generate a gross margin of R230 906, R193 676, R156 447 and R92 213 with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.2.5 *Summer Crop Mix 5*

Table F5 shows the response of maize (M benchmark) to reduced water availability level. The maize area would be reduced from 180 ha at 100 per cent water availability level to 135, 90 and 45 ha at 75, 50 and 25 per cent water availability level, respectively. The gross margin of R136 440, R102 330, R68 220 and R34 110 can be obtained with 100, 75, 50 and 25 per cent water availability level, respectively.

5.5.2.6 *Winter Crop Mix 1 - 4*

In Table F6 the response of wheat (Winter Crop Mix 1 – 4) on reduced water availability level is presented. The area allocated to wheat is reduced from 120 ha at 100 per cent water availability level, to 90, 60 and 30 ha at 75, 50 and 25 per cent water availability level. The gross margin of R276 960, R207 720, R138 480 and R69 240 can be achieved with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.2.7 *Winter Crop Mix 5*

Table F7 shows the response of winter benchmark, 180 ha of wheat, to reduced irrigation water levels. The area under the crop is reduced by the same margin as the water availability level, from 180 at 100 per cent to 135, 90 and 45 ha at 75, 50 and 25 per cent water availability level. The gross margin of R415 440, R311 580, R207 720 and R108 360 can be obtained with 100, 75, 50 and 25 per cent water availability level, respectively. The results for 240 ha farm under limited water availability levels are discussed next.

5.5.3 Optimum solution of water for summer season under limited irrigation water supply-240 ha farm

5.5.3.1 Summer Crop Mix 1

Table G1 shows the behaviour of maize, cotton and potatoes crop mix to reduced water supply. Cotton and potatoes are not sensitive to any reductions in water supply imposed. Hence the area allocated to these crops remain the same throughout the water reductions (water availability levels). Maize is very sensitive to reductions in water supply as its area decreases with decrease in water supply. The gross margin of R687 450, R644 463, R601 475 and R558 488 can be realised with 100, 75, 50 and 25 per cent water availability level, respectively.

5.5.3.2 Summer Crop Mix 2

In Table G2, the response of maize, lucerne and potatoes to reductions in available farm water supply is indicated. Maize is very sensitive to decrease in water supply because for every reduction imposed on water supply its area decrease drastically until the crc disappears from the optimal solution with 25 per cent water availability level or 75 per cent reduction in water supply. Lucerne responds to the lowest water availability level (highest reduction of 75 per cent in water supply) whereby its area is decreased from 30 to 26 ha. The cultivated area under potatoes remains unchanged regardless of reductions in water supply. The gross margin of R704 490, R657 169, R609, 849 and R556 993 can be obtained with 100, 75, 50 and 25 per cent water availability level, respectively.

5.5.3.3 Summer Crop Mix 3

Table G3 shows the response of maize, lucerne and groundnuts when irrigation water is reduced from 100 per cent to 75, 50 and 25 per cent water availability level, respectively. Maize is the most sensitive crop to reduced water supply conditions than the two other crops. This is indicated by the area under the crop, which decreases from 180 ha at 100 per cent water availability level to 115 and 49 ha with 75 and 50 per cent water availability level respectively. At 25 per cent water availability level, maize disappears from the optimal solution also the area under lucerne is reduced to 21 ha. Groundnuts are insensitive to any water reductions. For this crop mix, the gross margin of R307 530, R257 927, R208 324 and R146 324 can be obtained with 100, 75, 50 and 25 per cent water availability level respectively.

5.5.3.4 Summer Crop Mix 4

Table G4 shows the response of maize, lucerne and cotton to reduced water availability levels. The gross margin of R282 600, R232 447, R182 294 and R118 090 can be generated with 100, 75, 50, and 25 per cent water availability level, respectively.

5.5.3.5 Summer Crop Mix 5

Table G5 shows the response of maize (benchmark) when cultivated on full irrigated area (240 ha). The gross margin of R181 920, R136 440, R90 960, and R45 480 can be obtained at 100, 75, 50 and 25 per cent water availability level, respectively.

5.5.3.6 Winter Crop Mix 1 - 4

Table G6 shows the response of wheat (on 180 ha) to reduced water availability levels. The gross margin of R415 440, R311 580, R207 720 and R108 360 can be obtained at 100, 75, 50 and 25 per cent water availability level respectively.

5.5.3.7 Winter Crop Mix 5

Table G7 shows the response of wheat on 240 ha (W benchmark) to reduced water availability level. The gross margin of R553 920, R415 440, R276 960 and R138 480 can be obtained with 100, 75, 50 and 25 per cent water availability level respectively.

The most important feature about BEWAB system is that irrigation water should be applied to meet full water demands of a crop for maximum yield to be obtained (on condition that other production factors are conducive for the crop). Irrigation plays a crucial role in the area because rainfall is very limited and does not contribute much to the growth of crops. If irrigation water is not available to crops, no yield can be harvested. This implies that irrigation water should be readily available to crops for farmers to remain farming with crops. Where crop water demands are not fully met because of limitations in water supply, sub-optimal yield or no yield could result. To overcome the problem of harvesting sub-optimal yields because of limited irrigation water supply, farmers have to device strategies. Next are strategies that farmers would put in place if available irrigation water is limited to 75 per cent, 50 per cent and 25 per cent of full application in the short, medium and long terms.

5.6 Future water strategies of irrigating farmers on the Ramah Canal at Vanderkloof Dam

Farmers were asked about the strategies they would adopt if there is a 25 per cent, 50 per cent and 75 per cent reduction in their present water quota respectively. Furthermore, they were asked whether the increasing scarcity of water would cause them to change the cropping pattern which in the long run would require that they buy new capital investments to accommodate the new cropping mix or other new enterprises. This would help the policy makers in formulating new strategies to allocate irrigation water quota more efficiently to farmers in the study area. The water strategies and the relevant changes reported by the farmers are discussed below.

As mentioned in Chapter 3, irrigated farms on the Ramah Canal were grouped into three categories of less than 100 ha, 100 to 200 ha and more than 200 ha irrigation water rights, respectively. The average farm sizes of 75, 180 and 240 ha were used in LP model to determine optimal allocation of resource for each farm group. In this section 75, 180 and 240 ha farm are presented as small, medium, and large farm groups (or farmers) respectively.

5.6.1 Short-term irrigation water restrictions

a) Water quota restriction to 75 per cent of the current quota

When water quota is restricted to 75 per cent, farmers with less than 100 ha irrigation water rights (small farm group), responded that they will go bankrupt since their present income already is very little to cover most of the production costs. Farmers indicated that extra water would be bought from other farmers (if available). Alternatively, they would decrease planted area by about the margin as the restrictions and cut winter and summer crops by 25 per cent. Farmers who have already cultivated perennial crops indicated that they would maintain current irrigation on those crops.

Farmers with irrigation water rights of between 100 and 200 ha (medium farm group) mentioned that a 25 per cent reduction on present water quota will change their cropping pattern from maize and wheat to cotton, peanuts and other summer cash crops because such summer crops have better income and also utilise less water. Moreover, if additional water were available, it would be bought. It was also indicated that cultivated area under production would be reduced by the same percentage as the reduction itself.

The large farm group with greater than 200 ha water rights indicated that the current water quota restriction to 75 per cent, would compel them to decrease area under cultivation by the same margin as the restriction and also buy extra water from other farmers with excess. Some farmers mentioned that the gross margin analysis for potential crop in the area would be essential before considering alternative crops to produce. Furthermore, cultivated areas under wheat and late maize would be reduced since the two do not generate as much income as other cash crops namely cotton and peanuts.

In general, it was the consensus opinion of farmers that when the present water quota is restricted to 75 per cent the area cultivated to maize and wheat would be reduced by the same margin as the restriction itself. Area planted to cash crops would be increased and extra water would be bought.

b) *Water quota restriction to 50 per cent of current allocation*

When the water quota restriction to 50 per cent scenario was posed to different farmer groups, the small and medium size groups responded the same way as for 75 per cent restriction. Cultivated area under other cash crops would be increased whereas area under maize and wheat would be reduced by the same margin as the reduction. Also extra water would be bought. The response from the large farm owners was the same as that from the first two groups except for three farmers in this group who mentioned that instead of reducing area cultivated, they would stop farming or sell their farms.

c) *Water quota restriction to 25 per cent of current allocation*

With 75 per cent reduction on present irrigation water quota, small farmers mentioned that they would cut area on short-term crops and maintain irrigation on perennial crops. Three out of four medium size farmers said they would reduce area cultivated by the restriction percentage and plant more summer crops. One farmer in this group (medium size) indicated that he would sell his farm.

d) *Selling irrigation water rights temporarily*

Farmers belonging to different irrigation water right groups mentioned that regardless of the size of irrigation water quota restrictions imposed on them in the short run, they would not sell their irrigation water at all.

e) *Cultivated land without water rights*

When farmers were asked what they would do with the cultivated area if present water quota were restricted to 75 per cent, the small farmers said they would fallow land not in use or consult land restitution to have the land reserved for them until the restriction is over. Among the medium size farm owners only one farmer responded to the question that he would plant less area. Three other farmers in this medium size farm group refused to respond to the question. Large farmers had divided opinions. Three out of seven farmers mentioned they would fallow part of cultivated area not in use. Three indicated that they would sell their farms altogether and one said he would utilise full-irrigated area but apply less water to crops.

Farmers who would remain in farming regardless of restrictions imposed in the short-run mentioned that they would reduce cultivated area. Some also indicated that they would cut on labour and other fixed costs to be able to survive.

5.6.2 Medium-term irrigation water strategies

a) Reduction on water quota by 75 per cent

If 25 per cent reduction on irrigation water quota was to be imposed for 3 to 5 years, small farmers indicated that they would maintain irrigation on perennial crops such as sultanas and pecanuts, and would cut on annual cash crops (maize and wheat) by 25 per cent. Alternatively, they would resort to livestock production. According to them, the decision they would adopt would entirely depend on cash flow.

Medium size farmers pointed out that they would consider water conservation measures and reduce area planted without engaging themselves in the production of long-term crops. They further indicated that they would pursue the crop mix of wheat, popcorn and dry beans, peanuts, cotton and early maize. Four out of seven large farmers mentioned that they would sell their farms, and those prepared to remain with farming would reduce area cultivated to wheat and maize and introduce other cash crops including potatoes and groundnuts.

b) Determination of water price in the medium term.

When farmers were asked if they intend selling water in the medium term and how they would determine the price, large and medium size farmers said they would consider market price or opportunity cost of water. Small farmers mentioned that they would search for open market through auctioning, charge water tax price or the value of land plus water tariff.

5.6.3 Long-term irrigation water strategies

a) Long-run water scarcity and production changes

If water becomes scarcer in future in the long-run, small farmers mentioned that they would shift their cropping pattern to permanent crops such as pecanuts, vineyards and pasture, plant less annual cash crops such as maize and wheat; and finally consider livestock production. Medium size farmers showed that they would change their cropping mix to perennial crops (pecanuts, vineyard pistachio citrus and olives). Large farmers mentioned different strategies to approach water scarcity in the long run. One farmer said that he would leave his farms for the children to inherit. Three farmers mentioned that they would sell their farms using the market value, stop farming or go for perennial crops such as pecanuts and pistacchio nuts.

b) Additional capital investment requirements in the long run

Farmers who intend pursuing permanent crop production in the long run were not much conversant with the type and cost of infrastructure or inputs they would require as part of capital investments for new crop mix.

c) Selling water in the long run.

When farmers were asked whether they would ever consider selling water permanently in the long-run, three out of five large farmers indicated that they would sell irrigation water quota permanently with land if it is below the present one (water quota) which is 1100 mm or 11 000 m^3/ha. The price would range from R8 000/ha to R30 000/ha with the average of R15 000/ha for irrigated land with water rights.

Small farmers said that they would consider selling water quota permanently in the long run if it is below 600mm per hectare. Further, the price of water per hectare would be determined by subtracting infrastructure from the market value of land and would range from R3 750 to R30 000/ha of irrigated area. Farmers mentioned that they would resort to livestock farming after selling their water quota.

Medium size farmers on the other hand pointed out that they would sell their water if the present water quota is below half. Farmers in this category consider R30 000 per hectare a good price for selling their water including land.

5.7 SUMMARY OF THE RESULTS

5.7.1 Land

Land is fully utilised by all crop mixes on 75 and 240 ha farm respectively. With regard to 180 ha farm group, a little bit of land allocated for maize production is left unused in summer.

5.7.2 Labour

Regular labour is not a problem except during peak demands such as during harvesting and planting, when additional labour in form of casual labour is hired to assist.

5.7.3 Water

The model shows how much water each crop mix on different farm groups would demand. Apparently, peak demands for water are in January to March for summer crops and September to October for winter crops. For a 75 ha farm, the Summer Crop Mix 1 consisting of maize and lucerne would demand the highest quantity of water whereas Winter Crop Mix 1 – 4 would demand the lowest quantity of water. For a 180 ha farm, the Summer Crop Mix 4 consisting of maize, lucerne and cotton would demand the highest quantity of water whereas a Winter Crop Mix on 120, would demand the least quantity of water.

5.7.4 Tractor power

The highest demand for tractors is in December during land preparation and planting and also in April to May during harvesting of summer crops. All the three farm groups have more tractors than necessary, which are even under-utilised in peak periods. Over-investment on farm implements can lead to debt and liquidity problems in farms. Thus for 75 ha farm, one tractor can be enough for all the activities that need to be done on the farm except in December, April and May whereby two more tractors can be hired for land preparation, planting and harvesting. For a 180 ha farm, two tractors can be enough except for peak demands whereby two more tractors can be hired for that period. For 240 ha farm, four tractors can be enough under normal farm working conditions. But in peak demands, the 240 ha farmer can hire three extra tractors.

5.7.5 Crops

The sequence by which crops appear in the optimal solution depends on their contribution in maximising farm gross margin. Crops that contribute high gross margin, but demand less water are introduced first into irrigation. Hence, potatoes would be irrigated first followed by groundnuts, cotton, lucerne and maize in that sequence. When irrigation water is limited, maize would be the first crop to disappear from the optimal solution whereas potatoes would be the last one to disappear from the optimal solution. The MVP for water for different crops does not change regardless of change in crop mixes. This means that area allocated to each crop does not play any role in determining the value of each additional unit of water.

5.7.6 Future water management strategies

Farmers were asked about strategies they would pursue if water is limited in the short, medium and long terms. It was found that small farmers (farmers with irrigation water rights below 100 ha) are not afraid of facing any challenges of water shortages regardless of how severe or how long such water limitations could last. Farmers in this group regard selling water and land as the very last options. Medium farmers (100 – 200 ha irrigation water rights) are not very sure of the strategies to take if water shortages persist regardless of severity. Large farmers (farmers with at least 200 ha irrigation water rights) with high investments on farm on the other hand are very particular with changing water allocation strategies and will not wait for the worst scenario to happen. Instead, if water quota decrease persists, these farmers are prepared to quit farming and look for other means of livelihood.

CHAPTER 6

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY

Water is the most important limiting factor in the Ramah Canal hence, this situation hinders the expansion of irrigated agriculture in the area. Since agriculture is the main water consuming sector at the Ramah Canal, it must be prepared to respond to limitations in water resource by becoming more efficient in water use. Increase in efficiency of water use will require significant improvements in existing farm level irrigation management practices. A survey was conducted to determine the existing farming situation for the area. A farm level analysis was chosen to determine the economic effects when irrigation water is unconstrained and when the available irrigation water is limited. A model was developed to analyse how different crop mixes would respond under unconstrained and constrained irrigation water supply. The main objective of the study was to identify optimal irrigation water allocation strategies that farmers can use during winter and summer seasons to adjust to limited water supply in the Ramah Canal and to maximise gross income subject to a given set of constraints. To achieve this aim, certain sub objectives were developed. In this chapter, the summary of sub objectives in achieving the main objective is discussed. The conclusions for the study are drawn and recommendations made thereafter.

The first objective of the study was to classify farms into different water-use groups and to describe the groups according to irrigation water rights.

In section 3.2.1 irrigated farms in the Ramah Canal were classified according to irrigation water rights into three farm groups namely, farms with less than 100 ha, 100 to 200 ha and more than 200 ha irrigation water rights, respectively. For each farm group the average farm size was determined. Therefore, in section 3.4.1 of Chapter 3, the average farm size of 75, 180 and 240 ha were determined for farms with less than 100 ha, 100 to 200 ha and more than 200 ha irrigation water rights, respectively. These average farm sizes were used for the analyses in the study.

The second sub objective of the research was to determine whether economies of size exists for crop production.

The survey was conducted to determine the present farm situation in the Ramah Canal. The survey results are presented in Chapter 3. With information collected from the farmers by means of a questionnaire, income and balance sheet statements were compiled to determine the financial situation of the three farm groups. From these statements, different financial ratios such as solvency, liquidity, profitability and efficiency ratios were determined. The solvency status of the three farm groups was found to be good. This is indicated by the net capital ratios, which are above a benchmark of two and above, the leverage ratios which are below the norm of 1 and own capital ratios which are above a benchmark of 0.5. This implies that the farms in three farm groups have more assets than liabilities

The liquidity status of the farms as explained by current ratio and intermediate ratios was very poor. The current and intermediate ratios of three farm groups were below the norm of two and four and more, respectively. This implied that enough cash is not generated to redeem short-term liabilities. Therefore, if liabilities keep on piling, in the long run, farmers would encounter serious financial problems such as bankruptcy.

The profitability status of the farms is not satisfactory. The profitability on own capital is less than profitability on total capital employed (farm profitability). This means that farmers are encountering negative leverage and as a result have to use their own capital in order to meet interest and other liabilities.

The efficiency status as indicated by the cost ratio and the fixed turn over is very poor. The cost ratio for the three farm groups is far above the benchmark, which is 0.50 or less.

Also the fixed assets turn over for the three is below the benchmark or the norm which is 0.50.

The farm groups are highly solvent. This implies that farmers can improve financial status of the farms by converting fixed assets into current assets. By so doing, the current assets can be used to redeem the current liabilities and improve the liquidity status of the farms. Consequently, the profitability of the farm business will also improve. Other possible measures can be to reduce production on low value crops such as maize, which is the dominant crop in the area.

The ratios indicated that 180 ha farm group had the best liquidity, profitability and efficiency ratios. In the second position was 240 ha farm group with the second best solvency, liquidity, profitability and efficiency ratios. Therefore, the analysis indicated that economies of size exists between farms groups with 180 ha farm being the best size to operate on.

In the third objective of the study, Linear Programming model was constructed for different groups of farms in order to determine the impact of different water allocation regimes on farm decision making.

The LP model development and its components are discussed in Chapter 4. The linear programming model was developed to simulate crop production under summer and winter seasons when irrigation water is not a problem and under irrigation water supply limitations. Inputs into the model included gross margin which served as the objective function subject to water availability constraints (water requirement for each crop and total water available from the source), land area constraints in summer and winter seasons, labour constraints, tractor constraints and crop area constraints. The model maximised gross margin subject to a given set of constraints namely, labour, tractor power, crop area and irrigation water.

The fourth sub objective dealt with deriving optimal cropping mix to maximize farm net returns subject to unconstrained and limited irrigation water allocation.

Five optimal crop mixes (for summer and winter season) were determined for each farm group under unconstrained and limited irrigation water supply. The fifth crop mix for each farm consisted of all irrigated land made available to maize in summer and wheat in winter hence this crop mix was referred to as the benchmark. For each crop mix, optimal gross margin and optimal resource (irrigated area, water, labour and tractor power) allocation were obtained. Furthermore, the summer and winter total value product functions (gross margin as a function of water applied) were constructed for each crop mix under unconstrained irrigation water supply.

Empirical results for unconstrained irrigation water supply

The LP results for different crop mixes are presented by means of tables and graphs, which indicate the sequence by which crops would be irrigated based on their contribution in maximising cropping mix. In Chapter 5, the full results showing tables and graphs for a 75 ha farm are discussed. Tables and graphs for 180 ha and 240 ha farm group are attached in Appendices D and E, respectively. From the results, it is optimal to use all the available irrigated area for the production of different crop mixes on 75 and 240 ha farm. The results for 180 ha showed that it is optimal to use all the available irrigated area for other crop mixes except for Summer Crop Mix 3 and 4, whereby 18 ha and 8 ha of the area allocated to maize would remain unused respectively. In all the farm groups, there was over investment in tractor power. Labour was not a problem except in peak periods such as during harvesting of potatoes and groundnuts whereby casual labour is hired to assist regular labour.

Empirical results for limited irrigation water supply

Sensitivity analysis was conducted whereby the full water application required by various crop mixes was reduced from 100 per cent to 75, 50 and 25 per cent. Results from the LP for the three farm groups in Chapter 5 indicated that for summer season, maize was the most sensitive crop to limitations in water supply hence area allocated to the crop decreased with decrease in water supply. This implies that a lot of land can be left unused if these reductions in water supply prevail in the area in summer season. Otherwise farmers will have to look for high value crops such as pecanuts and other fruits that are efficient in water supply to replace maize. Lucerne is the second most sensitive crop to reductions in water supply after maize. In the third position is cotton followed by groundnuts, wheat and lastly potatoes.

The fifth sub objective determined the marginal value product (MVP) of irrigation water as a proxy for water price in the study area.

The optimal crop mixes were obtained for each farm group and their gross margins maximised subject to available resources. For each crop mix, the slopes of TVP function were estimated by expressing optimal gross margin as a function of water applied. The first derivative of the TVP function for each crop gave the MVP for that particular crop. The MVP for water for various crops were R3.64, R0.39, R0.38, R0.22, R0.18 and R0.09/m^3 for potatoes, wheat, groundnuts, cotton, lucerne and maize, respectively. This information showed how much a farmer could afford to pay for water required to produce an additional unit of a crop for immediate season. Although financial statements indicated that economies of size exists, these MVPs indicated that there were no economies with respect to the crops produced.

The last objective was aimed at investigating water management strategies that farmers would employ when subject to different irrigation water reduction levels in the short, medium and long terms.

Farmers' reactions were obtained for scenarios in which the present irrigation water quota is reduced by 25, 50 and 75 per cent in the short, medium and long term. The 75 ha farm group farmers indicated that they would reduce irrigated area by the same margin as the reduction in available water. Moreover, they would resort to high value cash crops such as pecanuts. Farmers on 180 ha farm size indicated that they would first reduce irrigated area by the same margin as the reduction in water supply. But with severe reduction in water supply, they would also resort to high value crops such as fruits. The farmers on 240 ha farm group indicated that with limitations in water supply, they would first reduce area allocated to the crops by the same margin as water supply. But, if reduction in water supply reduction persists, they would abandon their fields for other professions or leave farms for their children to inherit.

6.2 CONCLUSION

The financial analysis was done to determine the financial status of the farms and also to determine whether economies of scale exist in irrigated farming in the Ramah Canal. The results showed that there is existence of economies of scale. From the analysis, the 180 ha farm group can be regarded as the optimal farm size to operate for better profit whereas the small farm group is the least efficient. By changing production practices to high value crops for example, it is assumed that 75 ha farmers would be in a position to generate profit from a small unit of land which, will reduce liabilities and enhance profit. If water is used efficiently, better profit will be generated.

The response of farmers when irrigation water is limited in future was investigated. It was found that farmers in the 75 ha category are not afraid of facing any challenges of water shortages regardless of how severe or how long such water limitations could last. Farmers in this group regard selling water and land as the very last options. Farmers from 180 ha group are not very sure of the strategies to adopt if water shortages persist regardless of severity. Farmers in the 240 ha group are very particular with changing water allocation strategies and are prepared to quit farming and look for other means of livelihood.

The farm level optimisation model was developed to analyse producer decision in response to available water supply. The study was intended to determine the optimal cropping mix when irrigation water is sufficient to satisfy a given crop mix and when it is restricted. The model requires that crops be irrigated in sequence based on their profitability with the most profitable crops receiving preferential treatment or being considered first for irrigation. In summer season, potato was the most profitable crop and hence was considered first for irrigation. Maize was the last crop to be considered for irrigation because of it has the lowest profitability level. The next crop to be considered for irrigation was groundnut, which has the second highest gross margin. Cotton, lucern and maize followed groundnuts for irrigation in that order. In winter season, wheat was the only crop considered for irrigation.

It was found that the derived values of applied water (MVP for water) ranged from R0.09 to R3.64 and these MVPs are crop specific. Based on these MVPs it can be concluded that maize producing farmers cannot afford to pay more than R0.09 per unit of water required for immediate season. In contrast, farmers producing potatoes can afford to pay as much as R3.64 for additional unit of water required in the immediate season. Wheat, groundnuts, cotton and lucerne producing farmers can afford to pay R0.39, R0.38, R0.25 and R0.18, respectively for additional unit of water required to produce those crops.

The results further indicated that large reductions in water supply could result in more than fifty per cent loss in producer's income (with a lot of irrigated land left unused). The results showed how different crops included in different crop mixes respond to restricted and unrestricted irrigation water allocations. With this information, farmers can choose a crop mix based on both need and potential benefits that can be obtained from such a crop mix.

It can be concluded that, the LP model creates a quantitative basis for analysing seasonal responses of farmers and crop combinations to changes in irrigation water supply. The output obtained from the LP can be used as guidelines for assisting irrigation officers and farmers in making decision on the selection of crops and the allocation of planting area when irrigation water is limited and when it not a constraint. The study provided information and guidelines for choosing the best cropping strategy based on the available irrigation water and complementing production resources.

6.3 RECOMMENDATIONS

The study was based on one production year or two production seasons (summer and winter) whereas crop production in the area is continuous. It is therefore important to carry out the same study for a reasonably longer period of time (10 years).

The potential of also growing long term crops such as fruits and other high value crops instead of the present maize and wheat only should be investigated in the area. Production of long-term and high value crops could be a remedy for the poor performance of some farms especially small farms.

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APPENDIX A: QUESTIONNAIRE

GENERAL INFORMATION

NAME OF INTERVIEWER	
DATE OF INTERVIEW	
RESPONDENT'S NAME	
ADDRESS	
TELEPHONE NUMBER	
CELLPHONE NUMBER	
TOWN/VILLAGE/FARM	
QUESTIONNAIRE NUMBER	

SECTION A: ASSETS AND LIABILITIES

1. PROPERTY RIGHTS

PROPERTY NAME	SINCE WHEN WAS IT OWNED/ RENTED	TOTAL AREA (ha)	IRRIGATED AREA (ha)		YARDS, ROADS ETC.	TOTAL (ha)
			WITH RIGHTS*	WITHOUT RIGHTS*		
Own property						
Rented property						

*rights refer to water rights

2. ASSETS

2.1 LAND AND VALUE OF BUILDINGS

PROPERTY NAME	MARKET VALUE OF BUILDINGS (R)					MARKET VALUE OF LAND (R)			
	Managers housing	Farm building	Labour housing	Water supply (Movable)	Permanent irrigation*	Price/ha (A)	Total area (ha) (B)	Total market value = (A x B)	Rent/ha
Own land									
Rented land									

2.2 CAPITAL INVESTMENT

ITEM	CAPACITY (CC/kW)	MODEL	PURCHASED PRICE (R)	MARKET VALUE (R)	REMARKS
Motor cars					
1.					
2.					
3.					
4.					
5.					
Bakkies- LDV's					
1.					
2.					
3.					
4.					
5.					
Trucks					
1.					
2.					
3.					
4.					
5.					
Tractors					
1.					
2.					
3.					
4.					
5.					
Other self propelling machinery					
Combine harvesters					
Bull dozer					
Fork lift					
Ploughs					
1.					
2.					
3.					
4.					

ITEM	CAPACITY (CC/kW)	MODEL	PURCHASED PRICE (R)	MARKET VALUE (R)	REMARKS
Planter					
1.					
2.					
3.					
4.					
5.					
Cultivators					
1.					
2.					
3.					
Fertiliser spreader					
1.					
2.					
Harrows/Rake					
1.					
2.					
Trailers					
1.					
2.					
3.					
4.					
5.					
Balers					
1.					
2.					
3.					
Threshing machine					
1.					
2.					
3.					
Spraying equipment					
Boom sprayers					
Mist blowers					

Cont...

ITEM	CAPACITY (CC/kW)	MODEL	PURCHASED PRICE (R)	MARKET VALUE (R)	REMARKS
Peanut equipment					
1.					
2.					
3.					
4.					
5.					
Potato equipment					
Potato lifter					
Potato sorter					
Irrigation motors & pumps					
1.					
2.					
3.					
4.					
5.					
Motors & pumps for general use					
1.					
2.					
3.					
4.					
5.					
Office equipment					
1.					
2.					
3.					
4.					
5.					
Others					
1.					
2.					
3.					
4.					
5.					
6.					
7.					

2.1 OTHER INVESTMENTS

TYPE	AMOUNT/VALUE (R)	PERIOD
Cash in bank		
Savings account		
Fixed deposit		
Membership fees		
Debtors		
Shares		
Other fixed property		
Investment in farm house		
Others:		
TOTAL		

2.2 INVENTORY OF FARM PRODUCTS AND INPUTS

TYPE	VALUE
Lucerne/alfalfa	
Hay	
Crops on land	
Other:	
TOTAL FARM PRODUCTS	

FARM INPUTS

TYPE	VALUE (R)
Fertilizer	
Seeds	
Others:	
TOTAL FARM INPUTS	

3. LIABILITIES

3.1 SHORT-TERM, MEDIUM-TERM AND LONG-TERM

DESCRIPTION	PURPOSE	YEAR	AMOUNT (R)	AMOUNT OUTSTANDING (R)	AMOUNT PAID (R)	AMOUNT OWED (R)	INTEREST RATE (%)	PAYMENT	
								TIMES/YEAR	AMOUNT (R)
Short-term									
1.									
2.									
3.									
4.									
5.									
Medium-term									
1.									
2.									
3.									
4.									
5.									
Long-term									
1.									
2.									
3.									
4.									
5.									

3.2 ACCOUNTS

3.2.1 COOPERATIVES……………………………………………………………...

YEAR	MONTH	MONTHLY BALANCE (R)	INTEREST PAID (R)
	March		
	April		
	May		
	June		
	July		
	August		
	September		
	October		
	November		
	December		
	January		
	February		

3.2.2 COMMERCIAL BANK………………………………………………………...

YEAR	MONTH	MONTHLY BALANCE (R)	INTEREST PAID (R)
	March		
	April		
	May		
	June		
	July		
	August		
	September		
	October		
	November		
	December		
	January		
	February		

3.2.3 COMMERCIAL BANK II……………………………………………………...

YEAR	MONTH	MONTHLY BALANCE (R)	INTEREST PAID (R)
	March		
	April		
	May		
	June		
	July		
	August		
	September		
	October		
	November		
	December		
	January		
	February		

3. OTHER INCOME

ITEM	AMOUNT (R)
Contract work	
Bonuses	
Others:	
TOTAL	

5. FIXED FARM EXPENDITURE

5.1 LABOUR

5.1.1 Fixed labour

TYPE OF RENUMERATION	TOTAL COST (R)	
	PER MONTH	PER YEAR
Wages		
Farm product / ration		
Purchased ration		
Accident insurance		
Medical expenses		
Others		
TOTAL		

5.1.2 Casual labour

TYPE OF RENUMERATION	TOTAL COST (R)	
	PER MONTH	PER YEAR
Wages		
Farm product / ration		
Purchased ration		
Accident insurance		
Medical expenses		
Others		
TOTAL		

5.2 REPAIRS AND MAINTENANCE

ITEM	TOTAL COST (R)
Trucks	
Bakkies	
Tractors	
Implements	
Harvesting machinery	
Irrigation equipment	
Farm buildings	
Tyres, repairs and lubricants	
Others:	
TOTAL	

5.3 FARM INSURANCE / LICENCES

ITEM	TOTAL COST PER YEAR (R)	
	INSURANCE	LICENCES
Vehicles		
Farm machinery		
Buildings		
Others:		
TOTAL		

5.4 ADDITIONAL FARM EXPENDITURE

ITEM	TOTAL COST (R)	
	PER MONTH	PER YEAR
Welding and consumables		
Electricity		
Water tax		
District taxes		
Commissioner of casualty		
Accounting costs		
Banking costs		
Farm magazines		
Telephone and posting		
Association fees		
Income tax		
In arrears		
Prepaid		
Lease		
Creditors		
Rent fees		
Rented management		
Others:		
TOTAL		

4. HOUSEHOLD EXPENSES

ITEM	TOTAL COST (R)	
	PER MONTH	PER YEAR
Food and household consumables		
Clothing		
Medical expenses		
Electricity		
Telephone		
House maintenance		
Lease payment (private transfer)		
Hired house		
Fuel (private)		
Housemaid/labour)		
Services and repairs (private)		
Garden maintenance		
School fees		
University fees		
Holiday expenses		
Insurance fees:-		
House		
Car		
Life		
Private licenses		
Others		
TOTAL		

SECTION B: WATER QUOTA/CROP ROTATION SYSTEM

WATER QUOTA ENTITLEMENT..m^3/ha

SUMMER CROP ROTATION SYSTEM					
CROP	**TOTAL AREA (ha)**	**AVERAGE YIELD (tons/ha)**	**AREA UNDER IRRIGATION**		
			FLOOD (ha)	**SPRINKLER (ha)**	**OTHER SYSTEM (SPECIFY) (ha)**
Year 1					
Year 2					
Year 3					
Year 4					

WATER QUOTA ENTITLEMENT..m^3/ha

WINTER CROP ROTATION SYSTEM					
CROP	**TOTAL AREA (ha)**	**AVERAGE YIELD (tons/ha)**	**AREA UNDER IRRIGATION**		
			FLOOD (ha)	**SPRINKLER (ha)**	**OTHER SYSTEM (SPECIFY) (ha)**
Year 1					
Year 2					
Year 3					
Year 4					

PRODUCTION ACTIVITIES

SHORT-TERM: NEXT SEASON

ACTIVITIES	CROPS								
	EARLY MAIZE	**LATE MAIZE**	**WHEAT**	**DRY BEANS**	**PEAS**	**POTATOES**	**LUCERNE**	**COTTON**	**GROUNDNUTS**
Planting time									
Harvesting time									
Water application (m^3)									
January									
February									
March									
April									
May									
June									
July									
August									
September									
October									
November									
December									
TOTAL									
Average Yield (tons/ha)									

WATER MANAGEMENT STRATEGIES

I SHORT TERM STRATEGIES (1 -2 YEARS)

1. If the present water quota is restricted to	**75%**	**50%**	**25%**
What will your strategies be?	....	....	....
a) Will you sell the water temporarily?	Yes / No	Yes / No	Yes / No
b) What will you do with the land?	....	....	....

	75%	50%	25%
c) Will you reduce:-	Est.	Est.	Est.
Area planted?	Yes / No / ___ Ha	Yes / No / ___ Ha	Yes / No / ___ Ha
Seeds planted per hectare?	Yes / No / ___ Kg	Yes / No / ___ Kg	Yes / No / ___ Kg
Fertiliser application per hectare?	Yes / No / ___ Kg	Yes / No / ___ Kg	Yes / No / ___ Kg
Harvest costs per hectare	Yes / No / ___ R	Yes / No / ___ R	Yes / No / ___ R
d) Any other?	....	....	....

II MEDIUM-TERM STRATEGIES 3 TO 5 YEARS

1.0 Assume a 25% reduction in your quota for 3 – 5 consecutive years.

a) State your strategies:-

....

....

....

....

b) What crop combination will you pursue?

....

....

....

....

c) If you intend to sell water in the medium term how will you determine the price?

....

....

....

....

2.0 If the reductions in the present quota were between 25%-50% for 3 to 5 years, will your strategies in 1 change? Yes No

How?

....

....

....

....

a) Will your cropping combination be different? Yes No

How?

....

....

....

....

3.0 Any other decisions/suggestions regarding medium-term strategies?

....

....

....

....

III LONG-TERM STRATEGIES - MORE THAN 5 YEARS

1.0 If the water becomes scarcer in future (in the long run) what production changes will you pursue?

a) Will you change your cropping pattern from cash crops to perennial crops?

Yes | No

b) What perennial crops will you plant then (according to the order of priority?

1...

2...

3...

4...

5...

2.0 What additional capital investments will be required to produce the above mentioned crops?

PERENNIAL CROPS								
CROP 1			CROP 2			CROP 3		
Year	**Type**	**Amount (R)**	**Year**	**Type**	**Amount (R)**	**Year**	**Type**	**Amount (R)**
1								
2								
3								
4								
5								
6								

a) In the long run, will you decide to sell part of your water quota permanently?

Yes | No

b) What water quota will force you to arrive at this decision? ________ m^3/ha

3.0 Will you ever consider selling all your water quota permanently? | Yes | No |

a) If yes what water quota will force you to do that? [ ] m^3/ha

b) What will you consider as a good price to sell your water quota permanently? R.......

c) What will you do with your land when you have sold your water quota?

....

....

....

....

APPENDIX B: CROP ENTERPRISE BUDGETS

Table B1: Wheat enterprise budgets on the Ramah Canal at Vanderkloof Dam, 2000

	UNIT	PRICE OR COST/UNIT	QTY	VALUE/COST PER HA
GROSS RECEIPTS FROM PRODUCTION				
WHEAT	TON	1070.00	6	6420
TOTAL RECEIPTS			**6**	**6420**
PREHARVEST COSTS:				
SEED	KG	4.20	140	588.00
FUEL	L	3.20	57.6	184.32
FERTILIZER: STIKSTOF (nitrogenous)	KG	3.80	220	836.00
PHOSPHATE	KG	8.10	33	267.30
KCL	KG	3.50	40	140.00
MICROELEMENTS: Mn-Chil.BMX	KG	32.12	1	32.12
MANCOZIN	L	35.21	1	35.21
HERBICIDES: BROMOX	L	46.24	0.75	34.68
MCPA	L	24.36	0.5	12.18
GRASP	L	194.86	0.9	175.37
PESTICIDES: KARATE	L	263.00	0.13	34.19
FUNGICIDES: IMPACT (SWAMME)	L	107.76	1.5	161.64
ETAPON (OMVAL)	L	57.61	1.25	72.01
LUGBESPUIT (AEROPLANE)	HA	43.00	1	43.00
IRRIGATION POWER	RAND	0.53	660	349.80
WATER COST(R)	MM	0.17	660	112.20
LABOUR:	RAND	4.37	2.66	11.62
	RAND	3.13	0.69	2.16
	RAND	13.92	1	13.92
	RAND	96.86	1	96.86
	RAND	86.03	1	86.03
TOTAL PREHARVEST COST PER HA				**3288.62**
PRE-HARVEST COST PER BAG				**548.10**
HARVEST COSTS:				
HARVESTING COSTS	TON	350.00	1	350.00
CONTRACT TRANSPORT	TON	18.00	6	108.00
INTEREST ON OPERATING CAPITAL				153.34
INSURANCE				211.86
TOTAL HARVEST COST PER HA				**823.20**
HARVEST COST PER BAG				**137.20**
TOTAL ALLOCATED COSTS PER HA				**4111.82**
ALLOCATED COST PER BAG				**685.30**
GROSS MARGIN PER HECTARE				**2308.18**
GROSS MARGIN PER BAG				**384.70**

Table B2: Maize enterprise budgets on the Ramah Canal at Vanderkloof Dam, 2000

ITEM	UNIT	PRICE OR COST/UNIT	QTY	VALUE/COST PER HA
GROSS RECEIPTS FROM PRODUCTION				
MAIZE	TON	560.00	10	5600
TOTAL RECEIPTS			**10**	**5600**
PREHARVEST COSTS:				
SEED	PITTE	0.00775	85000	658.75
FUEL	L	3.20	110	352.00
FERTILIZER: STIKSTOF (nitrogenous)	KG	3.80	240	912.00
PHOSPHATE	KG	8.10	40	324.00
KCL	KG	3.50	50	175:00
MICROELEMENTS: Mn-Chil.BMX	KG	34.25	1	34.25
BORON	KG	14.12	1	14.12
ZINC CHELATE	KG	51.12	1	51.12
HERBICIDES: GALLEON x2	L	127.81	1.8	230.06
WENNER x2	L	84.58	1.6	135.33
PESTICIDE: ENDOSULPHUR (STALKBORER)	L			42.18
INSURANCE	TON			168.00
IRRIGATION POWER	RAND	0.55	750	412.50
WATER COST(R)	MM	0.20	700	140.00
WATER COST(R): DEVALUATION	RAND	90.07	1	90.07
LICENCE	RAND	13.36	1	13.36
IRRIGATION EQUIPMENT REPAIR	RAND	82.09	1	82.09
LABOUR	RAND	52.00	1	52.00
CASUAL LABOUR	RAND	15	5	75.00
TOTAL PREHARVEST COST PER HA				**3961.83**
PRE-HARVEST COST PER BAG				**396.18**
HARVEST COSTS:				
HARVEST COST	TON	405.00	1	405.00
CONTRACT TRANSPORT	TON	30.00	10	300.00
INTEREST ON OPERATING CAPITAL				174.80
TOTAL HARVEST COST PER HA				**879.80**
HARVEST COST PER BAG				**87.98**
TOTAL ALLOCATED COSTS PER HA				**4841.63**
ALLOCATED COST PER BAG				**484.16**
GROSS MARGIN PER HECTARE				**758.37**
GROSS MARGIN PER BAG				**75.84**

Table B3: Lucerne enterprise budgets on the Ramah Canal at Vanderkloof Dam, 2000

ITEM	UNIT	PRICE OR COST/UNIT	QTY	VALUE/COST PER HA
GROSS RECEIPTS FROM PRODUCTION				
LUCERNE	TON	420.00	12.86	5401.2
UNGRADED	TON	320.00	5.14	1644.8
TOTAL RECEIPTS			**18**	**7046**
PREHARVEST COSTS:				
SEED	KG	0.00	0	0.00
FUEL	L	3.20	148.8	476.16
FERTILIZER:STIKSTOF (nitrogenous)	KG	3.80	60	228.00
PHOSPHATE	KG	8.10	45	364.50
KCL	KG	3.50	50	175.00
HAYMAKING EQUIPMENT	RAND	0.00	1	0.00
HERBICIDES: CYSURE & INIBOOST	L	189.40	1.2	227.28
FUSALATE	L	108.82	2	217.64
DECIS	L	147.41	0.75	110.56
REPAIRS/MAINTENANCE	TON	291.18	1	291.18
IRRIGATION POWER	MM	0.54	1300	702.00
WATER COST(R)	MM	0.23	1300	299.00
LABOUR – PERMANENT	RAND	25.00	1.79	44.75
LABOUR – CASUAL	RAND	15.00	5	75.00
TOTAL PREHARVEST COST PER HA				**3211.07**
PRE-HARVEST COST PER BAG				**178.39**
HARVEST COSTS:				
HARVESTING COSTS	BALE	0.58	720	417.60
CONTRACT TRANSPORT	TON	30.00	18	540.00
INTEREST ON OPERATING CAPITAL				157.25
TOTAL HARVEST COST PER HA				**1114.85**
HARVEST COST PER BAG				**61.94**
TOTAL ALLOCATED COSTS PER HA				**4325.92**
ALLOCATED COST PER BAG				**240.33**
GROSS MARGIN PER HECTARE				**2720.08**
GROSS MARGIN PER BAG				**151.12**

Table B4: Groundnuts enterprise budgets on the Ramah Canal at Vanderkloof Dam, 2000

	UNIT	PRICE OR COST/UNIT	QTY	VALUE/COST PER HA
GROSS RECEIPTS FROM PRODUCTION				
GROUNDNUTS	TON	2931.80	2.5	7329.5
TOTAL RECEIPTS			**2.5**	**7329.5**
PREHARVEST COSTS:				
SEED	KG	6.00	150	900.00
FUEL	L	3.20	120	384.00
FERTILIZER: STIKSTOF (nitrogenous)	KG	3.80	120	456.00
PHOSPHATE	KG	8.10	25	202.50
KCL	KG	3.50	20	70.00
SODIUM MOLYBDATE	KG	93.67	0.25	23.42
MICROELEMENTS: Mn-Chil.BMX	HA	45.00	1	45.00
HERBICIDES: HAMMER	L	274.26	0.3	82.28
RELAY	L	68.90	1	68.90
PESTICIDES: KARATE	L	263.01	0.13	34.19
BRAVO	L	54.06	2	108.12
SANACARB: EELWORM	KG	33.96	10	339.60
IRRIGATION (POWER)	MM	0.53	580	307.40
WATER COST (R)	MM	0.22	580	127.60
TOTAL PREHARVEST COST PER HA				**3149.01**
PRE-HARVEST COST PER BAG				**1259.60**
HARVEST COSTS:				
LABOUR: PULLING	DAY	18.00	15	270.00
LABOUR: PICKING	DAY	18.00	8	144.00
LABOUR: HUSKING	DAY	18.00	10	180.00
CASUAL LABOUR	DAY	18.00	6	108.00
PACKAGING	BAG	1.36	50	68.00
CONTRACT TRANSPORT	TON	18.00	2.5	45.00
INSURANCE	TON			219.89
INTEREST ON OPERATING CAPITAL				162.10
TOTAL HARVEST COST PER HA				**1196.99**
HARVEST COST PER BAG				**478.80**
TOTAL ALLOCATED COSTS PER HA				**4346.00**
ALLOCATED COST PER BAG				**1738.40**
GROSS MARGIN PER HECTARE				**2983.50**
GROSS MARGIN PER BAG				**1193.40**

Table B5: Cotton enterprise budgets on the Ramah Canal at Vanderkloof Dam, 2000

ITEM	UNIT	PRICE OR COST/UNIT	QTY	VALUE/COST PER HA
GROSS RECEIPTS FROM PRODUCTION				
COTTON	KG	2.04	3800	7752
TOTAL RECEIPTS			**3800**	7752
PREHARVEST COSTS:				
SEED	KG	6.21	26	161.46
FUEL	L	3.20	115	368.00
FERTILIZER: STIKSTOF (nitrogenous)	KG	3.80	170	646.00
PHOSPHATE	KG	8.10	40	324.00
KCL	KG	3.50	50	175.00
HERBICIDES: TREFLAN	L	37.46	2	74.92
PESTICIDES: SANACARB	KG	150.00	1	150.00
KARATE	L	263.00	0.125	32.88
THIOFLO	L	62.76	1.85	116.11
CRACKER	L	34.35	3	103.05
BLADVAL	L	17.95	10	179.50
LUGBESPUITING	L	45.00	2	90.00
PIX X2	L	96.91	0.25	24.23
PIX	L	96.91	0.5	48.46
IRRIGATION POWER	RAND	0.55	850	467.50
WATER COST(R)	MM	0.25	850	212.50
LABOUR	DAY	15.00	4	60.00
TOTAL PREHARVEST COST PER HA				**3233.59**
PRE-HARVEST COST PER BAG				**0.85**
HARVEST COSTS:				
HARVESTING COST	KG	1000.00	1	1000.00
LABOUR	DAY	15.00	27	405.00
TRANSPORT	TON			20.00
INSURANCE	KG			733.25
INTEREST ON OPERATING CAPITAL				207.89
TOTAL HARVEST COST PER HA				**2366.14**
HARVEST COST PER BAG				**0.62**
TOTAL ALLOCATED COSTS PER HA				**5599.73**
ALLOCATED COST PER BAG				**1.47**
GROSS MARGIN PER HECTARE				**2152.27**
GROSS MARGIN PER BAG				**0.57**

Table B6: Potatoes enterprise budget on the Ramah Canal at Vanderkloof Dam, 2000

ITEM	UNIT	PRICE OR COST/UNIT	QTY	VALUE/COST PER HA
GROSS RECEIPTS FROM PRODUCTION				
POTATOES-BAG	25KG BAG	12.00	1750	21000
POTATO SEEDS – BAGS	10 KG BAG	36.00	700	25200
MINUS COMMISSION				2730
TOTAL RECEIPTS			**2450**	**43470**
PREHARVEST COSTS :				
SEED	25KG	44.50	160	7120.00
FUEL	L	3.20	175	560.00
FERTILIZER: STIKSTOF (nitrogenous)	KG	3.80	300	1140.00
PHOSPHATE	KG	8.10	100	810.00
KCL	KG	3.50	100	350.00
KNO3	KG	8.40	100	840.00
MICROELEMENTS: Mn-Chil.BMX	HA	150.00	1	150.00
CHEMICALS	HA	4991.34	1	4991.34
REGISTRATION COST	HA	444.03	1	444.03
IRRIGATION POWER	RAND	0.53	600	318.00
WATER COST(R)	MM	0.24	600	144.00
LABOUR	DAY	18.00	53	954.00
TOTAL PREHARVEST COST PER HA				**17821.37**
PRE-HARVEST COST PER BAG				**7.27**
HARVEST COSTS:				
LAB. REMOVE	DAY	15.00	20	300.00
LAB. SORT (SEED)	BAG	1.85	700	1295.00
LAB. SORT (TABLE)	BAG	0.80	1750	1400.00
PACKAGING: SEED	BAG	1.85	700	1295.00
TABLE	BAG	0.80	1750	1400.00
TRANSPORT: SEED	TONS	15.00	17.5	262.50
TABLE	BAG	1.35	1750	2362.50
INTEREST ON OPERATING CAPITAL				1118.57
TOTAL HARVEST COST PER HA				**9433.57**
HARVEST COST PER BAG				**3.85**
TOTAL ALLOCATED COSTS PER HA				**27254.94**
ALLOCATED COST PER BAG				**11.12**
GROSS MARGIN PER HECTARE				**16215.06**
GROSS MARGIN PER BAG				**6.62**

APPENDIXC: INCOME AND BALANCE SHEET STATEMENTS

Table C1: Income statement (Rand) for small farms (75 ha farm group) on the Ramah Canal at Vanderkloof Dam, 2000

GROSS FARM INCOME (GFI)										
CROPS	F1	F4	F9	F15	F17	TOTAL	MAX	MIN	AVERAGE	EFFICIENCY
Maize	448,500	201,600	336,000	246,400		1,232,500	448,500	201,600	308,125	849
Wheat	449,400	417,300	417,300	258,940		1,542,940	449,400	258,940	385,735	1,063
Lucerne (summer)	25,600				315,000	340,600	315,000	25,600	170,300	469
Vineyards				226,400		226,400	226,400	226,400	226,400	624
Peanuts		131,931				131,931	131,931	131,931	131,931	363
Sundry farm income	85,000			21,478		106,478	85,000	21,478	53,239	147
TOTAL GROSS FARM INCOME	**1,008,500**	**750,831**	**753,300**	**753,218**	**315,000**	**3,580,849**	**1,008,500**	**315,000**	**716,170**	**3,514**
PRODUCTION COSTS										
Variable costs	479,061	640,800	533,824	385,504	126,932	2,166,121	640,800	126,932	433,224	1,193
Fixed costs	168,300	179,801	138,940	209,122	154,280	850,443	209,122	138,940	170,089	469
TOTAL PRODUCTION COSTS	**647,361**	**820,601**	**672,764**	**594,626**	**281,212**	**3,016,564**	**820,601**	**281,212**	**603,313**	**1,868**
NET FARM INCOME / FARM PROFIT										
NET FARM INCOME (NFI)	**361,139**	**(69,770)**	**80,536**	**158,592**	**33,788**	**564,285**	**361,139**	**(69,770)**	**112,857**	**311**
less interest	80,365		127,083	42,559	37,060	287,067	127,083	37,060	71,767	198
FARM PROFIT (FP)	**280,774**	**(69,770)**	**(46,547)**	**116,033**	**(3,272)**	**277,218**	**280,774**	**(69,770)**	**55,444**	**153**
less household expenses	100,000	101,578	40,000	122,618	47,000	411,196	122,618	40,000	82,239	227
FARMERS' PROFIT	**180,774**	**(171,348)**	**(86,547)**	**(6,585)**	**(50,272)**	**(133,978)**	**180,774**	**(171,348)**	**(26,796)**	**(74)**

Abbreviation:
F1 = Farm 1

Table C2: Income statement (Rand) for medium farms (180 ha farm group) on the Ramah Canal at Vanderkloof Dam, 2000

GROSS FARM INCOME (GFI)									
CROPS	F3	F6	F8	F12	TOTAL	MAX	MIN	AVERAGE	EFFICIENCY
Maize	414,400	935,200	985,600	856,800	**3,192,000**	985,600	414,400	798,000	1,101
Wheat	869,375	1,072,140	1,059,300	996,170	**3,996,985**	1,072,140	869,375	999,246	1,379
Lucerne (summer)	113,400				**113,400**	113,400	113,400	113,400	157
Lucerne (winter)	113,400				**113,400**	113,400	113,400	113,400	157
Cotton	157,500				**157,500**	157,500	157,500	157,500	217
Peanuts	491,077				**491,077**	491,077	491,077	491,077	678
Dry peas	264,000				**264,000**	264,000	264,000	264,000	364
Potatoes			72,000		**72,000**	72,000	72,000	72,000	99
Sundry farm income			114,400		**114,400**	114,400	114,400	114,400	158
TOTAL GROSS FARM INCOME	**2,423,152**	**2,007,340**	**2,231,300**	**1,852,970**	**8,514,762**	**2,423,152**	**1,852,970**	**2,128,690**	**2,938**
PRODUCTION COSTS									
Variable inputs	1,469,261	1,495,226	1,589,386	982,697	**5,536,570**	1,589,386	982,697	1,384,143	1,910
Fixed costs	363,900	595,050	402,536	446,231	**1,807,717**	595,050	363,900	451,929	624
TOTAL PRODUCTION COSTS	**1,833,161**	**2,090,276**	**1,991,922**	**1,428,928**	**7,344,287**	**2,090,276**	**1,428,928**	**1,836,072**	**2,534**
NET FARM INCOME/FARM PROFIT									
NET FARM INCOME	589,991	(82,936)	239,378	424,042	**1,170,475**	**589,991**	**(82,936)**	**292,619**	**404**
less interest	356,720	143,520	173,465	258,395	**932,100**	356,720	143,520	233,025	322
FARM PROFIT	233,271	(226,456)	65,913	165,647	**238,375**	**233,271**	**(226,456)**	**59,594**	**82**
less household expenses	74,400	104,960	98,200	222,457	**500,017**	222,457	74,400	125,004	173
FARMERS' PROFIT	**158,871**	**(331,416)**	**(32,287)**	**(56,810)**	**(261,643)**	**158,871**	**(331,416)**	**(65,411)**	**(90)**

Abbreviation:
F1 = Farm 1

Table C3: Income statement (Rand) for large farms (240 ha farm group) on the Ramah Canal at Vanderkloof Dam, 2000

GROSS FARM INCOME(GFI)												
CROPS	F2	F5	F7	F11	F13	F14	F16	TOTAL	MAX	MIN	AVERAGE	EFFICIENCY
Maize	767,722	1,458,240	1,720,727	1,008,000	1,321,600	1,101,200	482,160	7,859,649	1,720,727	482,160	1,122,807	642
Wheat	1,046,285	1,123,500	1,843,227	1,155,600	1,515,120	1,250,000	622,954	8,556,686	1,843,227	622,954	1,222,384	699
Lucerne (summer)		117,600		3,780			226,800	348,180	226,800	3,780	116,060	66
Lucerne (winter)		117,600						117,600	117,600	117,600	117,600	67
Cotton	1,284,093							1,284,093	1,284,093	1,284,093	1,284,093	734
Pasture	6,704							6,704	6,704	6,704	6,704	4
Sundry farm income	284,300	12,000	200,000				804	497,104	284,300	804	124,276	71
TOTAL GROSS FARM INCOME	**3,389,104**	**2,828,940**	**3,763,954**	**2,167,380**	**2,836,720**	**2,351,200**	**1,332,718**	**18,670,016**	**3,763,954**	**1,332,718**	**2,667,145**	**1,525**
PRODUCTION COSTS												
Variable costs	1,382,185	1,528,000	2,071,009	1,313,656	1,764,000	1,376,200	540,071	9,975,121	2,071,009	540,071	1,425,017	815
Fixed costs	1,230,594	511,720	678,011	365,197	662,440	542,000	537,847	4,527,809	1,230,594	365,197	646,830	370
TOTAL PRODUCTION COSTS	**2,612,779**	**2,039,720**	**2,749,020**	**1,678,853**	**2,426,440**	**1,918,200**	**1,077,918**	**14,502,930**	**2,749,020**	**1,077,918**	**2,071,847**	**1,185**
NET FARM INCOME/FARM PROFIT												
NET FARM INCOME	**776,325**	**789,220**	**1,014,934**	**488,527**	**410,280**	**433,000**	**254,800**	**4,167,086**	**1,014,934**	**254,800**	**595,298**	**340**
less interest		29,000	263,653	166,505	132,900	513,800	130,459	1,236,317	513,800	29,000	206,053	118
FARM PROFIT	**776,325**	**760,220**	**751,281**	**322,022**	**277,380**	**(80,800)**	**124,341**	**2,930,769**	**776,325**	**(80,800)**	**418,681**	**239**
less household expenses	160,000	90,950	189,059	102,120	97,995	73,400	171,068	884,592	189,059	73,400	126,370	72
FARMERS' PROFIT	**616,325**	**669,270**	**562,222**	**219,902**	**179,385**	**(154,200)**	**(46,727)**	**2,046,177**	**669,270**	**(154,200)**	**292,311**	**167**

Abbreviation:
F1 = Farm 1

Table C4: **Balance sheet (Rand) for small farms (75 ha farm group) on the Ramah Canal at Vanderkloof Dam, 2000**

LIABILITIES									
ITEMS	F1	F4	F9	F15	F17	TOTAL	MAX	MIN	AVERAGE
Short term liabilities	196,000	540,000	370,000	276,700	1,030,000	2,412,700	1,030,000	196,000	482,540
Medium term liabilities			251,500	1,306	76,000	328,806	251,500	1,306	109,602
Long term liabilities	345,000		600,000	309,928	158,000	1,412,928	600,000	158,000	353,232
TOTAL LIABILITIES	**541,000**	**540,000**	**1,221,500**	**587,934**	**1,264,000**	**4,154,434**	**1,264,000**	**540,000**	**830,887**

ASSETS									
Current assets									
Other investments(short)	74,000	280,000		185,768		**539,768**	280,000	74,000	179,923
Inventory (inputs & products)	927,000	681,000	840,000	672,440	42,500	**3,162,940**	927,000	42,500	632,588
TOTAL	**1,001,000**	**961,000**	**840,000**	**858,208**	**42,500**	**3,702,708**	**1,001,000**	**42,500**	**740,542**
Medium term assets									
Capital assets	831,100	1,590,700	964,000	748,754	117,300	**4,251,854**	**1,590,700**	**117,300**	**850,371**
Fixed assets									
Land and buildings	1,800,000	1,435,000	1,900,000	2,257,200	1,197,500	8,589,700	2,257,200	1,197,500	1,717,940
Other investments (fixed)	106,000	425,000	207,000	406,830		1,144,830	425,000	106,000	286,208
TOTAL	**1,906,000**	**1,860,000**	**2,107,000**	**2,664,030**	**1,197,500**	**9,734,530**	**2,664,030**	**1,197,500**	**1,946,906**
TOTAL ASSETS	**3,738,100**	**4,411,700**	**3,911,000**	**4,270,992**	**1,357,300**	**17,689,092**	**4,411,700**	**1,357,300**	**3,537,818**
NET WORTH	**3,197,100**	**3,871,700**	**2,689,500**	**3,683,058**	**93,300**	**13,534,658**	**3,871,700**	**93,300**	**2,706,932**

Abbreviation:
F1 = Farm 1

Table C5: Balance sheet (Rand) for medium farms (180 ha farm group) on the Ramah Canal at Vanderkloof Dam, 2000

LIABILITIES

ITEMS	F3	F6	F8	F12	TOTAL	MAX	MIN	AVERAGE
Short term liabilities	600,000	114,000	1,120,000	611,000	2,445,000	1,120,000	114,000	611,250
Medium term liabilities	674,000	468,000	866,000		2,008,000	866,000	468,000	669,333
Long term liabilities	1,630,000		180,000	1,476,544	3,286,544	1,630,000	180,000	1,095,515
TOTAL LIABILITIES	**2,904,000**	**582,000**	**2,166,000**	**2,087,544**	**7,739,544**	**2,904,000**	**582,000**	**1,934,886**

ASSETS

ITEMS	F3	F6	F8	F12	TOTAL	MAX	MIN	AVERAGE
Current assets								
Other investments(short)	160,000	340,000	49,600	773,000	**1,322,600**	773,000	49,600	330,650
Inventory (inputs & products)	1,080,000	948,000	134,000	1,214,500	**3,376,500**	1,214,500	134,000	844,125
TOTAL	**1,240,000**	**1,288,000**	**183,600**	**1,987,500**	**4,699,100**	**1,987,500**	**183,600**	**1,174,775**
Medium term assets								
Capital assets	999,000	2,331,600	1,418,700	607,600	5,356,900	**2,331,600**	**607,600**	**1,339,225**
Fixed assets								
Land and buildings	2,956,000	3,910,000	3,520,000	6,000,000	16,386,000	6,000,000	2,956,000	4,096,500
Other investments(fixed)		74,000	820,000	285,000	1,179,000	820,000	74,000	393,000
TOTAL	**2,956,000**	**3,984,000**	**4,340,000**	**6,285,000**	**17,565,000**	**6,285,000**	**2,956,000**	**4,391,250**
TOTAL ASSETS	**5,195,000**	**7,603,600**	**5,942,300**	**8,880,100**	**27,621,000**	**8,880,100**	**5,195,000**	**6,905,250**
NET WORTH	**2,291,000**	**7,021,600**	**3,776,300**	**6,792,556**	**19,881,456**	**7,021,600**	**2,291,000**	**4,970,364**

Abbreviation:
F1 = Farm 1

Table C6: Balance sheet (Rand) for large farms (240 ha farm group) on the Ramah Canal at Vanderkloof Dam, 2000

LIABILITIES											
ITEMS	F2	F5	F7	F11	F13	F14	F16	TOTAL	MAX	MIN	AVERAGE
Short term liabilities	968,397	1,251,000	1,662,511	861,970	2,360,800	1,721,000	632,177	9,457,855	2,360,800	632,177	1,351,122
Medium term liabilities			900,000	952,000	855,000	580,000	272,000	3,559,000	952,000	272,000	711,800
Long term liabilities		200,000	894,717	10,104		200,000	273,127	1,577,948	894,717	10,104	315,590
TOTAL LIABILITIES	**968,397**	**1,451,000**	**3,457,228**	**1,824,074**	**3,215,800**	**2,501,000**	**1,177,304**	**14,594,803**	**3,457,228**	**968,397**	**2,084,972**

ASSETS											
Current assets											
Other investments(short)	350,000		115,000	393,000			86,118	**944,118**	393,000	86,118	236,030
Inventory (inputs & products)	1,720,000	1,020,000	3,728,500	1,140,200	4,441,520	1,300,000	565,680	**13,915,900**	4,441,520	565,680	1,987,986
TOTAL	**2,070,000**	**1,020,000**	**3,843,500**	**1,533,200**	**4,441,520**	**1,300,000**	**651,798**	**14,860,018**	**4,834,520**	**651,798**	**2,224,015**
Medium term assets											
Capital assets	2,119,200	1,607,500	4,254,085	1,650,000	2,607,000	1,287,000	2,331,600	15,856,385	4,254,085	1,287,000	2,265,198
Fixed assets											
Land and buildings	5,399,000	5,810,000	8,000,000	8,070,000	8,378,250	6,911,700	3,255,973	45,824,923	8,378,250	3,255,973	6,546,418
Other investments (fixed)	1,100,000		5,402,613	1,226,900		360,000	34,096	8,123,609	5,402,613	34,096	1,624,722
TOTAL	**6,499,000**	**5,810,000**	**13,402,613**	**9,296,900**	**8,378,250**	**7,271,700**	**3,290,069**	**53,948,532**	13,402,613	3,290,069	7,706,933
TOTAL ASSETS	**10,688,200**	**8,437,500**	**21,500,198**	**12,480,100**	**15,426,770**	**9,858,700**	**6,273,467**	**84,664,935**	**21,500,198**	**6,273,467**	**12,094,991**
NET WORTH	**9,719,803**	**6,986,500**	**18,042,970**	**10,656,026**	**12,210,970**	**7,357,700**	**5,096,163**	**70,070,132**	**18,042,970**	**5,096,163**	**10,010,019**

Abbreviation:
F1 = Farm 1

APPENDIX D: OPTIMAL CROP AREAS AND RESULTING GROSS MARGIN FOR 180 HA FARM UNDER UNCONSTRAINED IRRIGATION WATER SUPPLY

Table D1: **Optimal areas and resulting gross margin for maize, cotton and potatoes crop combination under unconstrained water supply on 180 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 1, 2001**

Water applied	Area selected per crop (ha)			Gross margin
(m^3)	Potatoes	Cotton	Maize	(R)
0	0			0
20,000	5			72,876
40,000	9			145,753
60,000	14			218,629
80,000	18			291,506
100,000	23			364,382
120,000	27			437,258
133,500	30			486,450
140,000	30	1		488,073
180,000	30	4		493,066
200,000	30	8		503,052
240,000	30	12		513,038
280,000	30	17		523,024
320,000	30	22		533,010
360,000	30	26		542,996
392,000	30	30		551,010
400,000	30	30	1	551,725
600,000	30	30	25	569,834
800,000	30	30	49	587,950
1,000,000	30	30	73	606,062
1,200,000	30	30	97	624,175
1,396,500	30	30	120	641,970

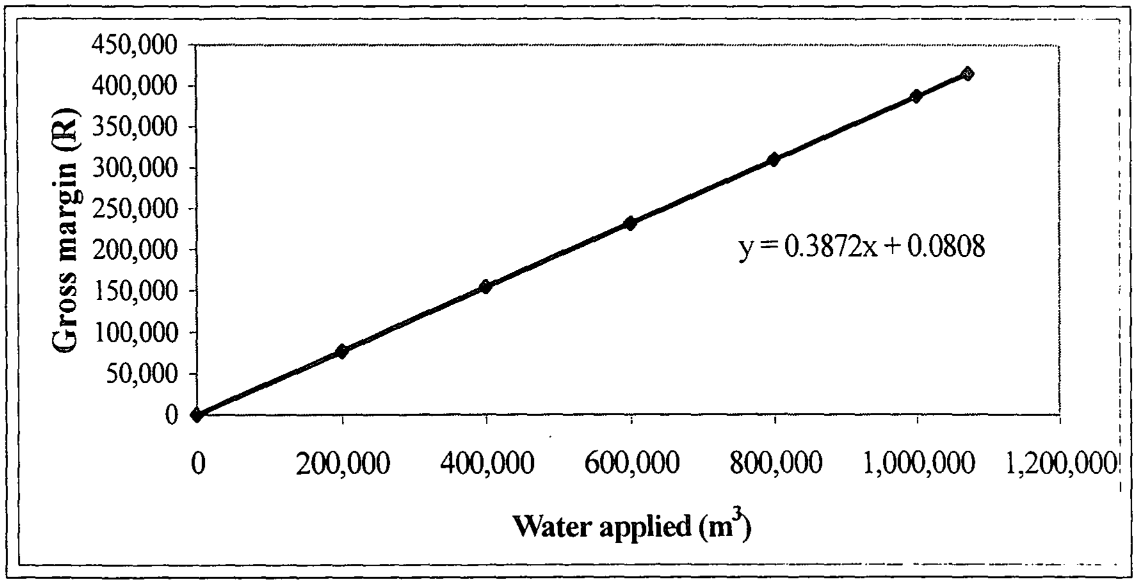

Figure D1: **Gross margin as a function of water applied for maize, cotton and potatoes, combination produced in the Ramah Canal at Vanderkloof Dam- Summer Crop Mix 1, 2001**

Table D2: **Optimal crop areas and resulting gross margin for maize, lucerne and potatoes crop combination under unconstrained water supply on 180 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 2, 2001**

Water applied	Area selected per crop (ha)			Gross margin
(m^3)	Potatoes	Lucerne	Maize	(R)
0	0			0
20,000	5			72,876
40,000	9			145,753
60,000	14			218,629
80,000	18			291,506
100,000	23			364,382
120,000	27			437,258
133,500	30			486,450
150,000	30	1		489,442
200,000	30	4		498,509
300,000	30	11		516,622
400,000	30	18		534,775
500,000	30	24		552,909
584,000	30	30		568,050
600,000	30	30	3	569,544
800,000	30	30	27	587,657
1,000,000	30	30	51	605,769
1,200,000	30	30	74	623,881
1,400,000	30	30	98	641,994
1,588,500	30	30	120	659,010

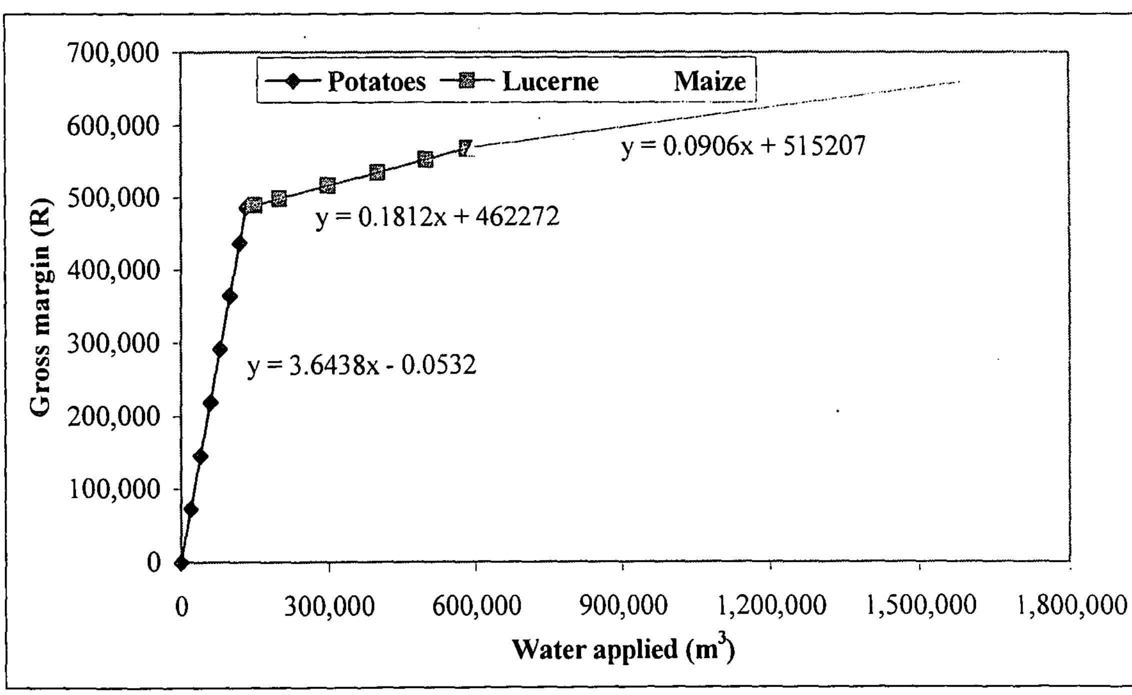

Figure D2: **Gross margin as a function of water applied for maize, lucerne and potatoes, combination produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001**

Table D3: Optimal crop areas and resulting gross margin for maize, lucerne and groundnuts crop combination under unconstrained water supply on 180 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001

Water applied	Area selected per crop (ha)			Gross margin
(m^3)	Groundnuts	Lucerne	Maize	(R)
0				0
40,000	5			15,278
80,000	10			30,556
120,000	15			45,834
160,000	21			61,111
200,000	26			76,389
234,300	30			89,490
240,000	30	0		90,524
280,000	30	3		97,777
300,000	30	4		101,404
400,000	30	11		119,537
500,000	30	18		137,670
600,000	30	24		155,804
684,300	30	30		171,090
700,000	30	30	2	172,512
800,000	30	30	14	181,568
1,000,000	30	30	38	199,680
1,200,000	30	30	62	217,793
1,400,000	30	30	86	235,905
1,534,684	30	30	102	248,102

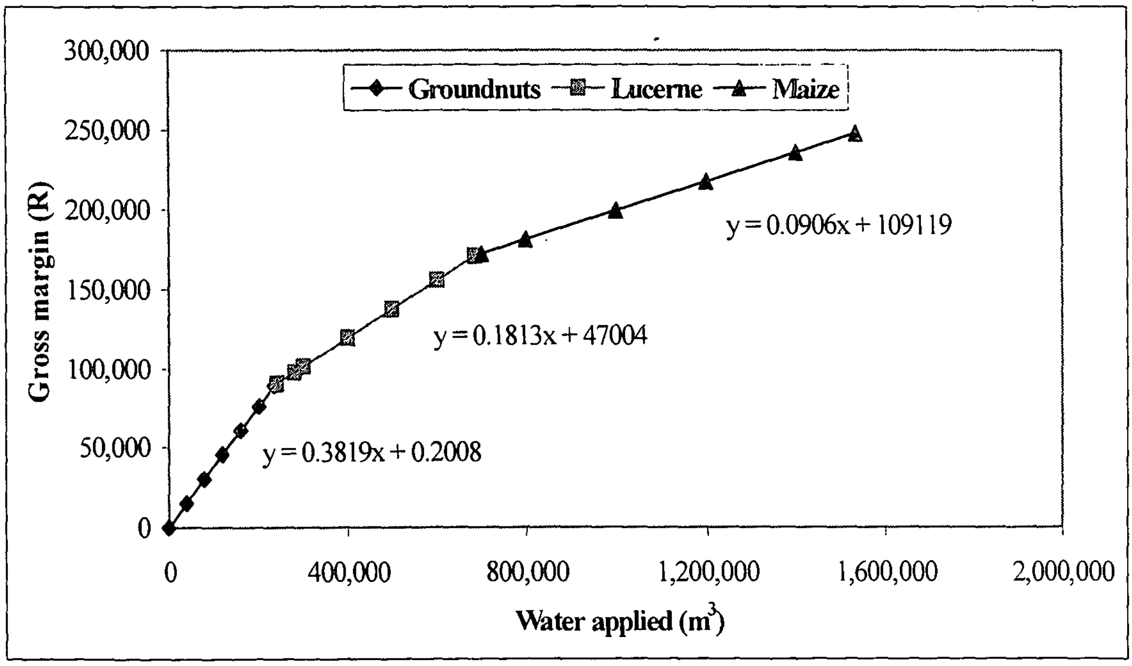

Figure D3: Gross margin as a function of water applied for maize, lucerne and groundnuts, combination produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001

Table D4: **Optimal crop areas and resulting gross margin for maize, lucerne and cotton crop combination under unconstrained water supply on 180 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 4, 2001**

Water applied	Area selected per crop (ha)			Gross margin
(m^3)	Cotton	Lucerne	Maize	(R)
0	0			0
50,000	6			12,483
100,000	12			24,965
150,000	17			37,448
200,000	23			49,930
250,000	29			62,413
258,600	30			64,560
300,000	30	3		72,067
400,000	30	9		90,201
500,000	30	16		108,334
600,000	30	23		126,467
700,000	30	29		144,601
708,600	30	30		146,160
750,000	30	30	5	149,909
800,000	30	30	11	154,437
1,000,000	30	30	35	172,550
1,200,000	30	30	59	190,662
1,400,000	30	30	83	208,774
1,600,000	30	30	107	226,887
1,644,383	30	30	112	230,906

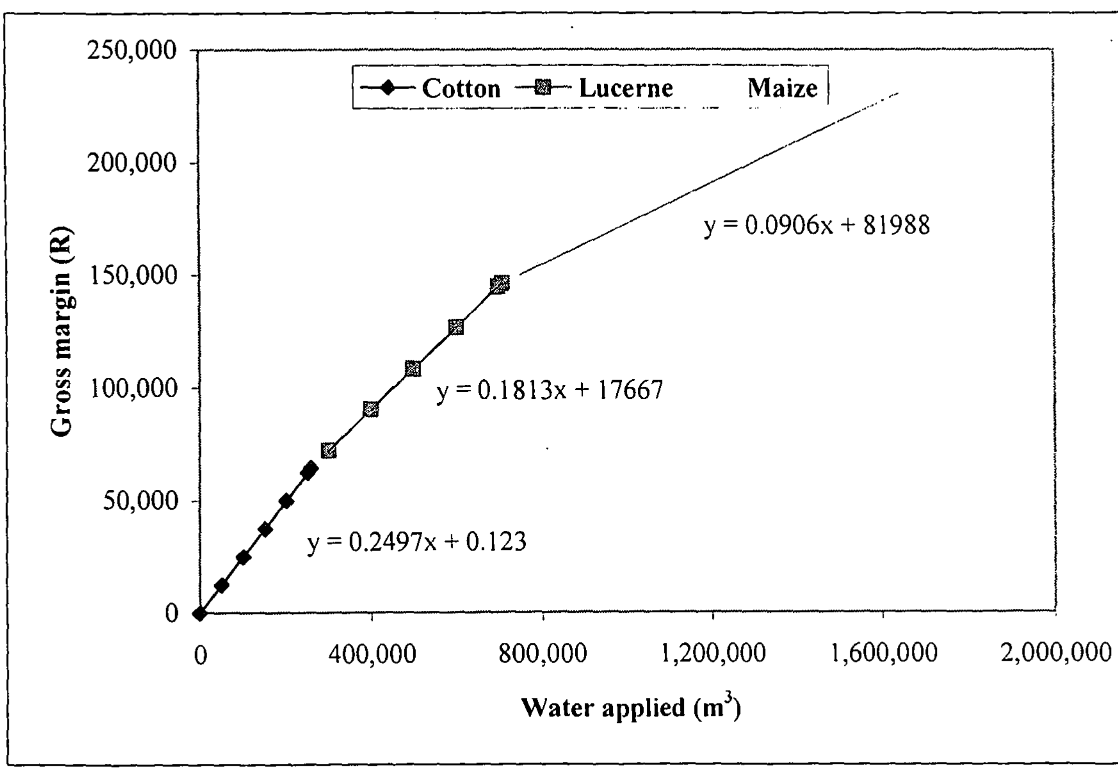

Figure D4: **Gross margin as a function of water applied for maize, lucerne and cotton, combination produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 4, 2001**

Table D5: Optimal crop areas and resulting gross margin for a 180 ha farm under unconstrained water supply in the Ramah Canal at Vanderkloof Dam- Summer Crop Mix 5, 2001

Water applied (m^3)	Area selected (ha)	Gross margin (R)
0		0
200,000	24	18,112
400,000	48	36,225
600,000	72	54,337
800,000	96	72,449
1,000,000	120	90,562
1,200,000	143	108,674
1,400,000	167	126,786
1,506,600	180	136,440

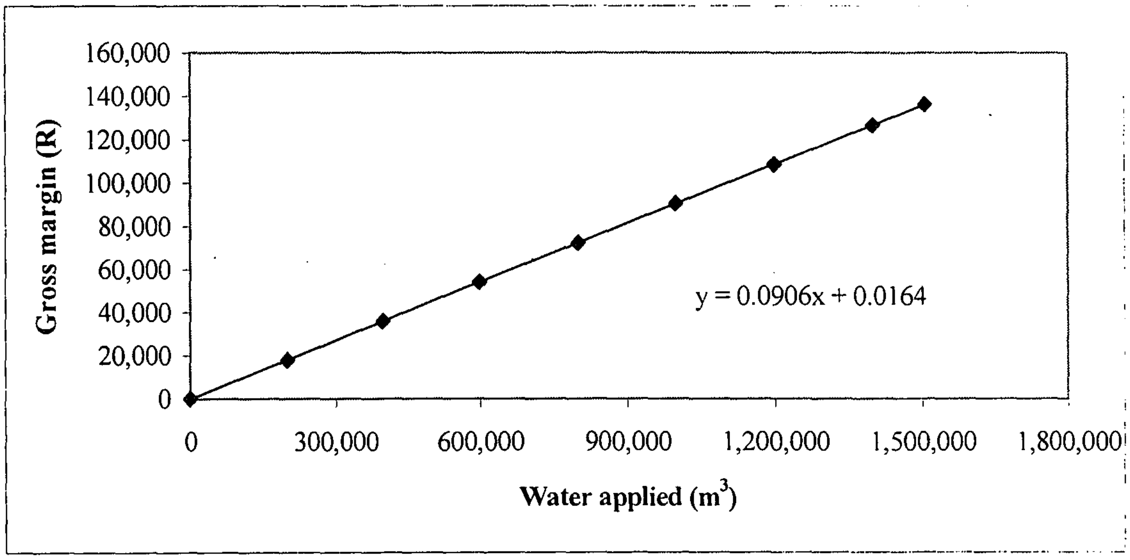

Figure D5: Gross margin as a function of water applied for maize (M benchmark) produced in the Ramah Canal at Vanderkloof Dam –Summer Crop Mix 5, 2001

Table D6: **Optimal crop areas and resulting gross margin for wheat under unconstrained water supply on 180 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 1 - 4, 2001**

Water applied (m^3)	Area allocated (ha)	Gross Margin (R)
0		0
200,000	34	77,450
400,000	67	154,899
600,000	101	232,349
715,200	120	276,960

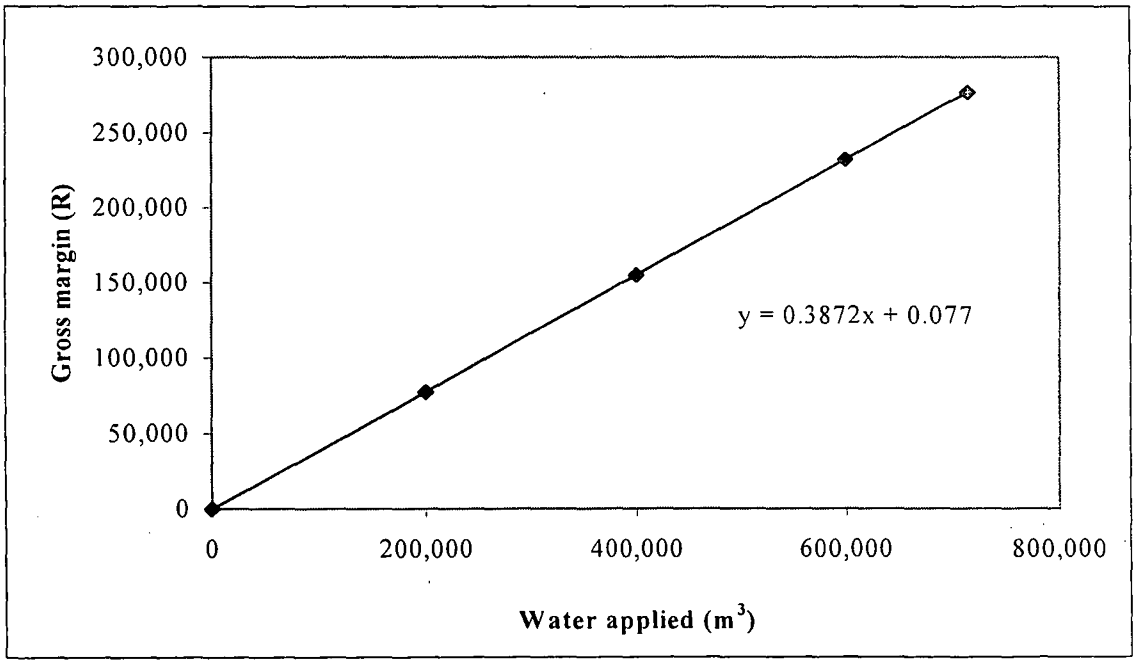

Figure D6: **Gross margin as a function of water applied for wheat (as winter crop) produced in the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 1 - 4, 2001**

Table D7: Optimal crop areas and resulting gross margin for wheat under unconstrained water supply on 180 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 5, 2001

Water applied (m^3)	Area allocated (ha)	Gross Margin (R)
0		0
200,000	34	77,450
400,000	67	154,899
600,000	101	232,349
715,200	120	276,960
800,000	134	309,799
1,000,000	168	387,248
1,072,800	180	415,440

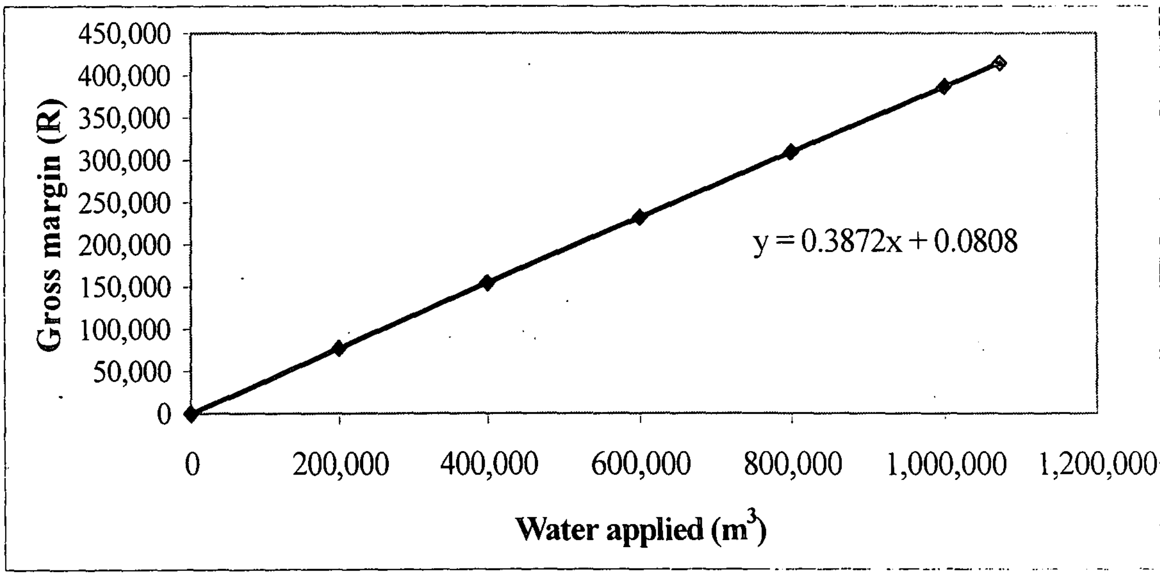

Figure D7: Gross margin as a function of water applied for wheat (as winter crop) produced in the Ramah Canal at Vanderkloof Dam – Winter Crop 5, 2001

APPENDIX E: OPTIMAL CROP AREAS AND RESULTING GROSS MARGIN FOR 240 HA FARM UNDER UNCONSTRAINED IRRIGATION WATER SUPPLY

Table E1: **Optimal crop areas and resulting gross margin for maize, cotton and potatoes combination under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam Summer Crop Mix 1, 2001**

Water applied	Area selected per crop (ha)			Gross margin
(m^3)	Potatoes	Cotton	Maize	(R)
0	0			0
20,000	5			72,876
40,000	9			145,753
60,000	14			218,629
80,000	18			291,506
100,000	23			364,382
120,000	27			437,258
133,500	30			486,450
140,000	30	1		488,073
180,000	30	4		493,066
200,000	30	8		503,052
240,000	30	12		513,038
280,000	30	17		523,024
320,000	30	22		533,010
360,000	30	26		542,996
392,000	30	30		551,010
400,000	30	30	1	551,725
600,000	30	30	25	569,834
800,000	30	30	49	587,950
1,000,000	30	30	73	606,062
1,200,000	30	30	97	624,175
1,400,000	30	30	121	642,284
1,600,000	30	30	144	660,399
1,898,700	30	30	180	687,450

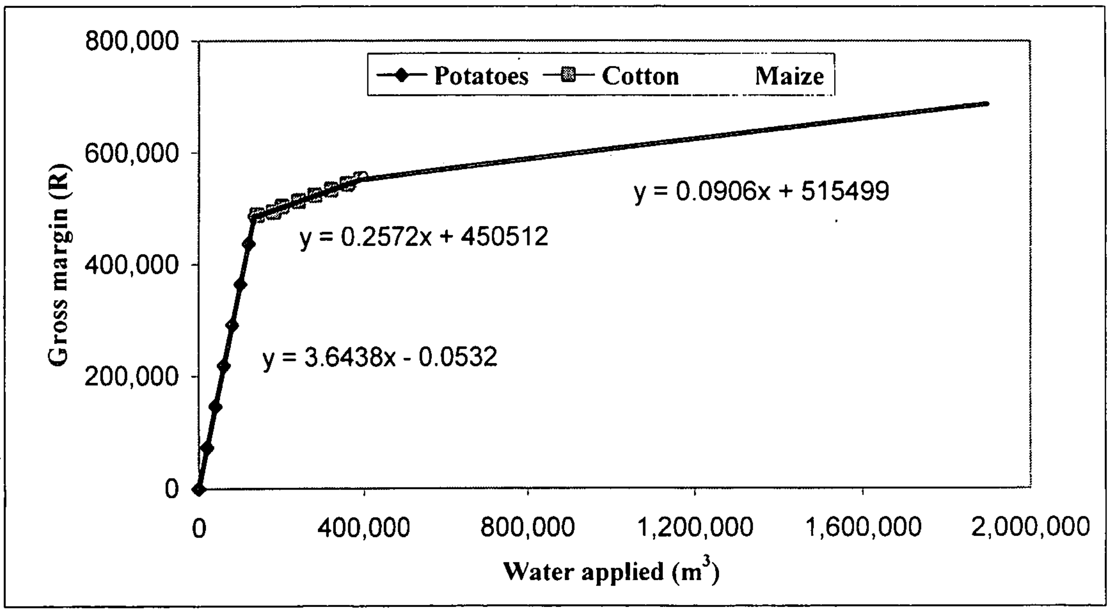

Figure E1: **Gross margin as a function of water applied for maize, cotton and potatoes, combination produced in the Ramah Canal at Vanderkloof Dam Summer Crop Mix 1, 2001**

Table E2: Optimal crop areas and resulting gross margin for maize, lucerne and potatoes crop combination under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 2, 2001

Water applied (m^3)	Area selected per crop (ha)			Gross margin (R)
	Potatoes	Lucerne	Maize	
0	0			0
20,000	5			72,876
40,000	9			145,753
60,000	14			218,629
80,000	18			291,506
100,000	23			364,382
120,000	27			437,258
133,500	30			486,450
150,000	30	1		489,442
200,000	30	4		498,509
300,000	30	11		516,622
400,000	30	18		534,775
500,000	30	24		552,909
584,000	30	30		568,050
600,000	30	30	3	569,544
800,000	30	30	27	587,657
1,000,000	30	30	51	605,769
1,200,000	30	30	74	623,881
1,400,000	30	30	98	641,994
1,600,000	30	30	121	660,106
2,000,000	30	30	169	696,330
2,090,100	30	30	180	704,490

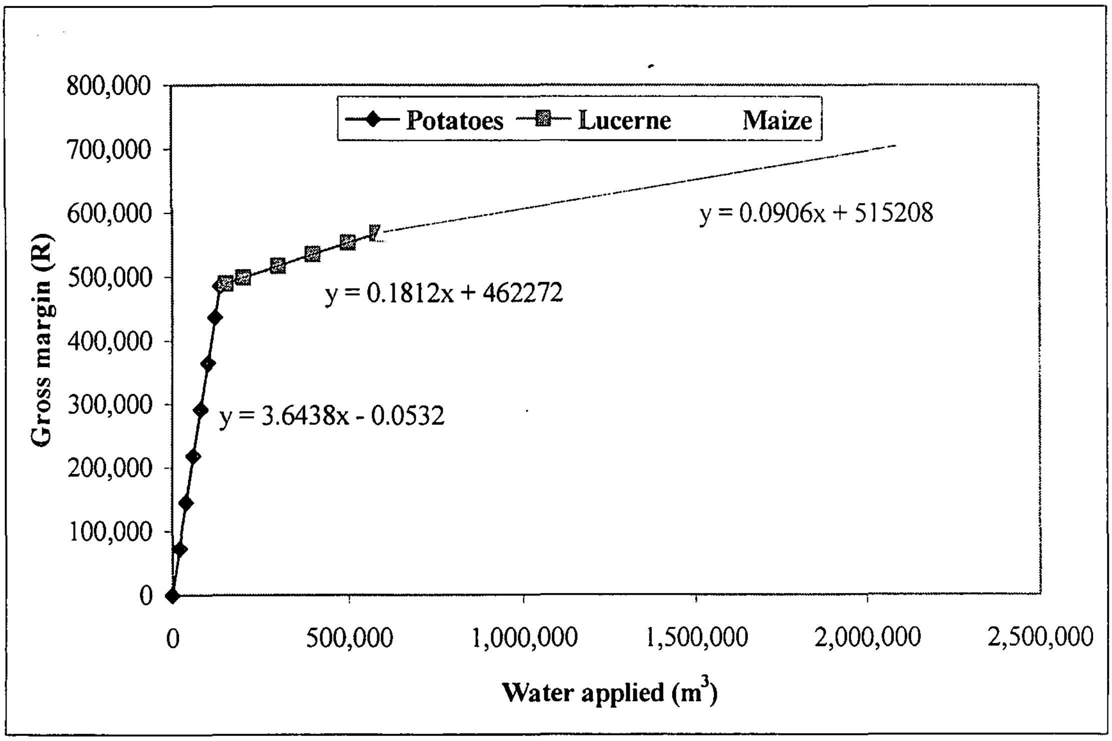

Figure E2: Gross margin as a function of water applied for maize, lucerne and potatoes, combination produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 2, 2001

Table E3: **Optimal crop areas and resulting gross margin for maize, lucerne and groundnuts crop combination under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001**

Water applied (m^3)	Area selected per crop (ha) Groundnuts	Lucerne	Maize	Gross margin (R)
0				0
40,000	5			15,278
80,000	10			30,556
120,000	15			45,834
160,000	21			61,111
200,000	26			76,389
234,300	30			89,490
240,000	30	0		90,524
280,000	30	3		97,777
300,000	30	4		101,404
400,000	30	11		119,537
500,000	30	18		137,670
600,000	30	24		155,804
684,300	30	30		171,090
700,000	30	30	2	172,512
800,000	30	30	14	181,568
1,000,000	30	30	38	199,680
1,200,000	30	30	62	217,793
1,600,000	30	30	109	254,017
2,000,000	30	30	157	290,242
2,190,900	30	30	180	307,530

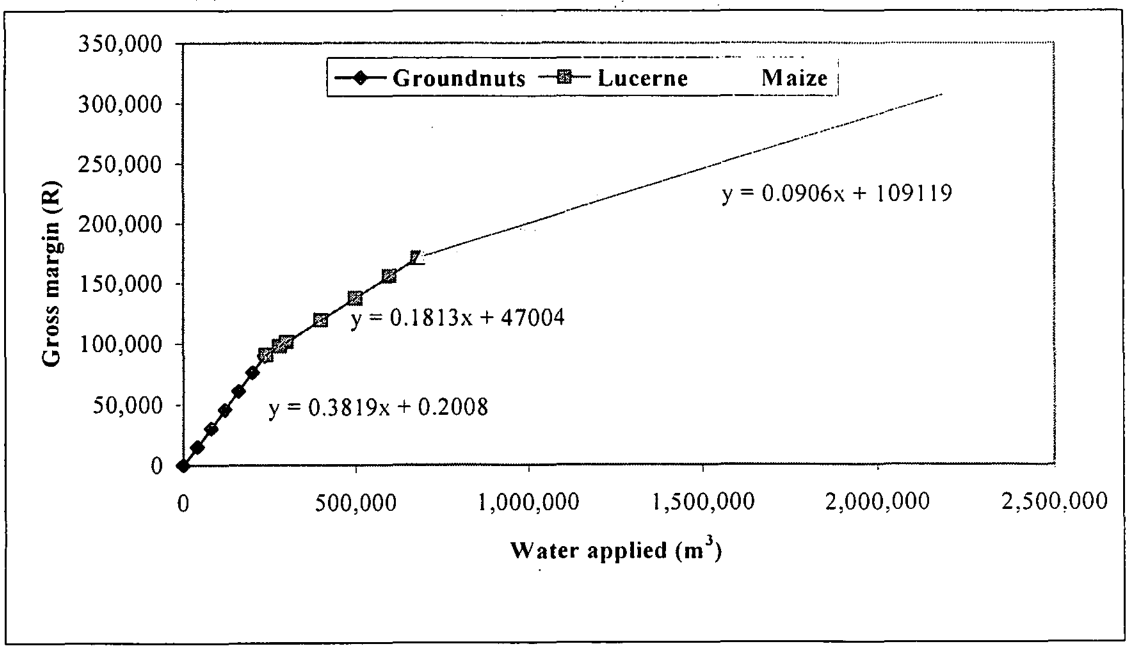

Figure E3: **Gross margin as a function of water applied for maize, lucerne and groundnuts, combination produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001**

Table E4: **Optimal crop areas and resulting gross margin for maize, lucerne and cotton crop combination under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 4, 2001**

Water applied (m^3)	Area selected per crop (ha)			Gross margin (R)
	Cotton	Lucerne	Maize	
0	0			0
50,000	6			12,483
100,000	12			24,965
150,000	17			37,448
200,000	23			49,930
250,000	29			62,413
258,600	30			64,560
300,000	30	3		72,067
400,000	30	9		90,201
500,000	30	16		108,334
600,000	30	23		126,467
700,000	30	29		144,601
708,600	30	30		146,160
750,000	30	30	5	149,909
800,000	30	30	11	154,437
1,000,000	30	30	35	172,550
1,200,000	30	30	59	190,662
1,400,000	30	30	83	208,774
1,600,000	30	30	107	226,887
2,000,000	30	30	154	263,111
2,215,200	30	30	180	282,600

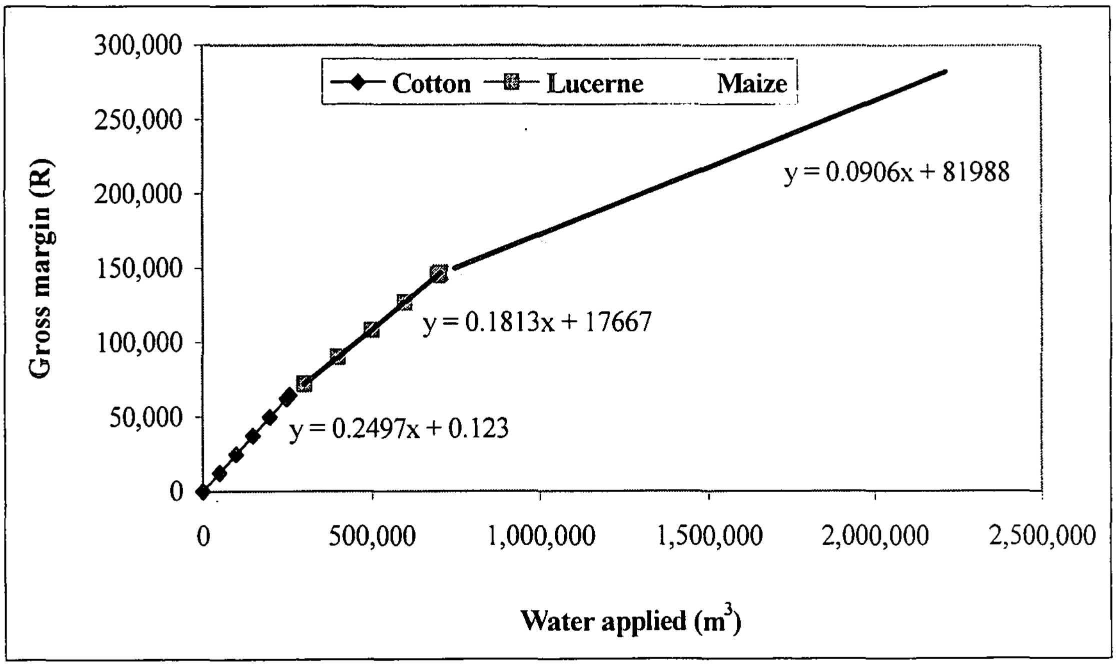

Figure E4: **Gross margin as a function of water applied for maize, lucerne and cotton, combination produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 4, 2001**

Table E5: **Optimal crop areas and resulting gross margin under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 5, 2001**

Water applied (m^3)	Area (ha)	Gross Margin (R)
0		0
400,000	48	36,225
800,000	96	72,449
1,200,000	143	108,674
1,600,000	191	144,898
2,000,000	239	181,123
2,008,800	240	181,920

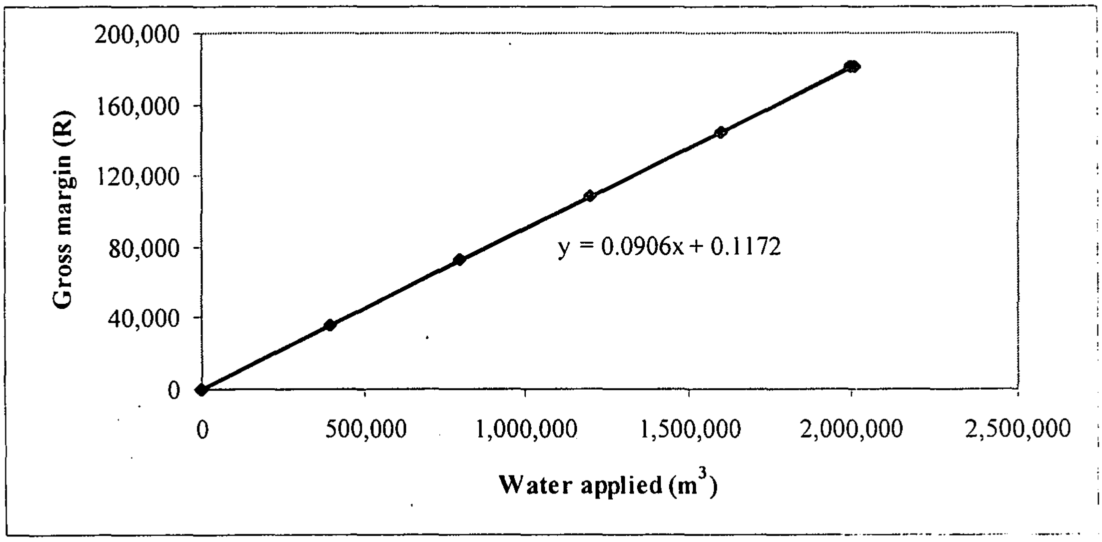

Figure E5: **Gross margin as a function of water applied for maize on 240 ha farm produced in the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 5, 2001**

Table E6: **Optimal crop areas and resulting gross margin for wheat under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 1 - 4, 2001**

Water applied (M^3)	Area selected (ha)	Gross Margin (R)
0		0
200,000	34	77,450
400,000	67	154,899
600,000	101	232,349
800,000	134	309,799
1,000,000	168	387,248
1,072,800	180	415,440

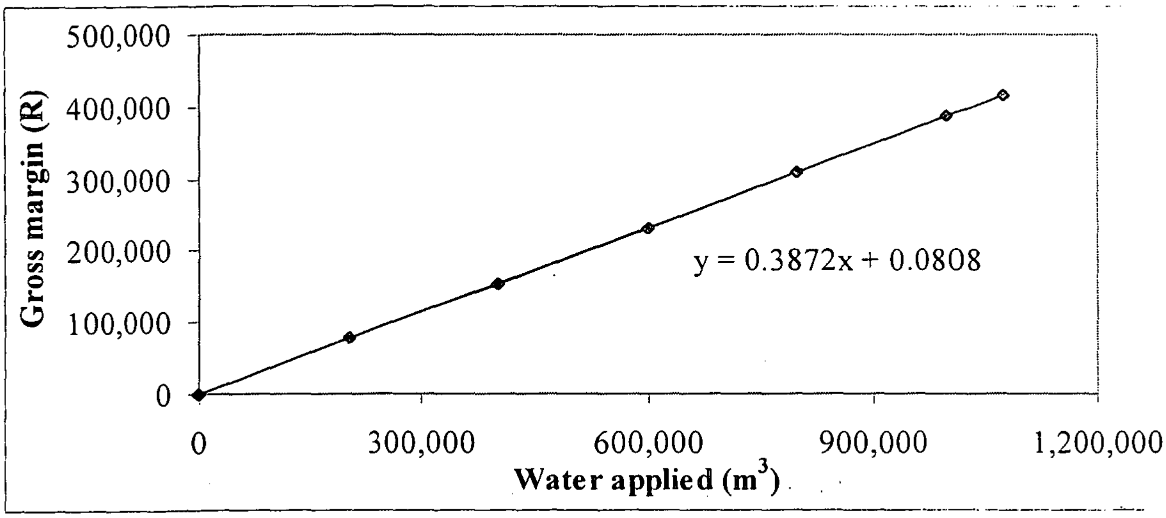

Figure E6: **Gross margin as a function of water applied for wheat (as winter crop) on 240 ha farm produced in the Ramah Canal at Vanderkloof Dam – Winter Crop mix 1 - 4, 2001**

Table E7: **Optimal crop areas and resulting gross margin for wheat under unconstrained water supply on 240 ha irrigated farm in the Ramah Canal at Vanderkloof Dam – Winter Crop Mix 5, 2001**

Water applied (m^3)	Area (ha)	Gross Margin (R)
0		0
200,000	34	77,450
400,000	67	154,899
600,000	101	232,349
800,000	134	309,799
1,000,000	168	387,248
1,200,000	201	464,698
1,400,000	235	542,148
1,430,400	240	553,920

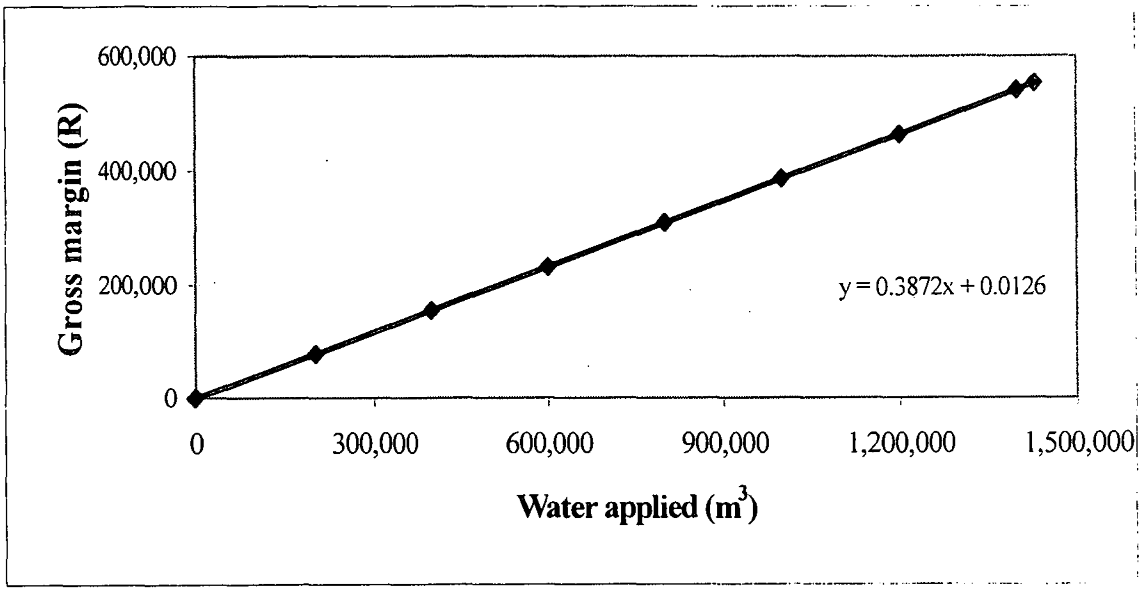

Figure E7: **Gross margin as a function of water applied for wheat on 240 ha farm produced in the Ramah Canal at Vanderkloof Dam – Winter Crop 5, 2001**

APPENDIX F: OPTIMAL CROP AREA AND RESULTING GROSS MARGIN FOR 180 HA FARM UNDER LIMITED IRRIGATION WATER SUPPLY

Table F1: **Optimal crop areas and resulting gross margin for a 180 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 1, 2001**

Water availability level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	C	P	
100%	1,396,500	120	30	30	641,970
75%	1,047,375	78	30	30	610,353
50%	698,250	37	30	30	578,735
25%	349,125	0	25	30	540,281

Table F2: **Optimal crop areas and resulting gross margin for a 180 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 2, 2001**

Water availability level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	L	P	
100%	1,587,900	120	30	30	659,010
75%	1,190,925	73	30	30	623,059
50%	793,950	25	30	30	587,109
25%	396,975	18	25	30	534,227

Table F3: **Optimal crop areas and resulting gross margin for a 180 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 3, 2001**

Water availability Level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	L	G	
100%	1,534,684	120	30	30	248,102
75%	1,151,013	56	30	30	213,356
50%	767,342	10	30	30	178,910
25%	383,671	0	10	30	116,576

Table F4: Optimal crop areas and resulting gross margin for a 180 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 4, 2001

Water availability Level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	L	C	
100%	1,644,383	120	30	30	230,906
75%	1,233,287	63	30	30	193,676
50%	822,192	14	30	30	156,447
25%	411,096	10	30	30	92,213

Table F5: Optimal crop areas and resulting gross margin for a 180 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 5, 2001

Water availability Level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	1,506,600	180	136,440
75%	1,129,950	135	102,330
50%	753,300	90	68,220
25%	376,650	45	34,110

Table F6: Optimal crop areas and resulting gross margin for a 75 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Winter Crop (1 -4), 2001

Water availability level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	715,200	120	276,960
75%	536,400	90	207,720
50%	357,600	60	138,480
25%	178,800	30	69,240

Table F7: **Optimal crop areas and resulting gross margin for a 180 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Winter Crop Mix 5, 2001**

Water availability level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	1,072,800	180	415,440
75%	804,600	135	311,580
50%	536,400	90	207,720
25%	268,200	45	108,360

APPENDIX G: OPTIMAL CROP AREA AND RSULTING ROSS MARGIN FOR 240 HA FARM UNDER LIMITED IRRIGATION WATER SUPPLY

Table G1: **Optimal crop areas and resulting gross margin for a 240 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 1, 2001**

Water availability Level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	C	P	
100%	1,898,700	180	30	30	687,450
75%	1,424,025	123	30	30	644,463
50%	949,350	67	30	30	601,475
25%	474,675	10	30	30	558,488

Table G2: **Optimal crop areas and resulting gross margin for a 240 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 2, 2001**

Water availability Level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	L	P	
100%	2,090,100	180	30	30	704,490
75%	1,567,575	118	30	30	657,169
50%	1,045,050	55	30	30	609,849
25%	522,525	0	26	30	556,993

Table G3: **Optimal crop areas and resulting gross margin for a 240 ha farm under limited water supply at the Ramah Canal at Vanderkloof Dam – Summer Crop Mix 3, 2001**

Water availability level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	L	G	
100%	2,190,900	180	30	30	307,530
75%	1,643,175	115	30	30	257,927
50%	1,095,450	49	30	30	208,324
25%	547,725	0	21	30	146,324

Table G4: **Optimal crop areas and resulting gross margin for a 280 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 4, 2001**

Water availability level	Total water available (m^3)	Area selected per crop (ha)			Gross margin (R)
		M	L	C	
100%	2,215,200	180	30	30	282,600
75%	1,661,400	114	30	30	232,447
50%	1,107,600	48	30	30	182,294
25%	553,800	0	20	30	118,090

Table G5: **Optimal crop areas and resulting gross margin for a 240 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Summer Crop Mix 5, 2001**

Water availability level	Total water available (m^3)	Area selected (ha)	Gross margin (R)
100%	2,008,800	240	181,920
75%	1,506,600	180	136,440
50%	1,004,400	120	90,960
25%	502,200	60	45,480

Table G6: **Optimal crop areas and resulting gross margin for a 240 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Winter Crop (1 – 4), 2001**

Water availability level	Total water available (m^3)	Area Selected (ha)	Gross margin (R)
100%	1,072,800	180	415,440
75%	804,600	135	311,580
50%	536,400	90	207,720
25%	268,200	45	108,360

Table G7: Optimal crop areas and resulting gross margin for a 240 ha farm under limited water supply at the Ramah Canal, Vanderkloof Dam – Winter Crop Mix 5 (benchmark), 2001

Water availability Level	Total water Available (m^3)	Area Selected (ha)	Gross margin (R)
100%	1,430,400	240	553,920
75%	1,072,800	180	415,440
50%	715,200	120	276,960
25%	357,600	60	138,480