ALTERNATIVE INSTITUTIONAL ARRANGEMENTS TOWARDS OPTIMAL WATER ALLOCATION

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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EMMANUEL FOSTER YAO GAKPO

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ABSTRACT

The limited natural availability of water resources in South Africa coupled with the increasing competition between water users demands that, reallocation and sustainable use of water be given serious attention.

Bringing into perspective factors leading to the vulnerability of water resources, focus is placed on institutional issues, which is becoming a thorny issue nationally. Drawing on institutional economic theory a generic water institutional framework is developed to assist in shaping institutional arrangements towards achieving economic and social objectives simultaneously, in order to guarantee water security.

In this thesis an ideal institutional framework was developed and used in conjunction with global trends and patterns in water policy and institutional arrangements, to evaluate the South African water law and water policy. The evaluation revealed that factors like: excessive government control of water management institutions; bureaucratic consented water reallocations; administratively set pricing mechanisms; lack of appropriate arrangements to facilitate tradable entitlements (like defining exclusive rights to entitlements); unclear water transfer arrangements; and lack of definitive institutional provisions for integrated demand and supply management, deviate from current international water institutional trends and also fall short of an ideal institutional arrangement that will lead to water security.

The weaknesses in the current South African water laws and policies prompted the search for alternative institutional arrangements, which particularly have the potential to offer more opportunities for effective water allocation and management, and largely based on decentralisation and full stakeholder participation.

A number of alternatives were studied and Capacity Sharing (CS) was identified as the most appropriate. Capacity sharing is an institutional arrangement with property rights structured to allocate water among multiple users of water resource systems. This form of institutional arrangement provides each user or group of users of *reservoir water with perpetual or long-term rights to a percentage of reservoir inflows and a percentage of reservoir storage capacity.*

Capacity Sharing has the capacity to solve the potential South African water scarcity problem, because of its dependence on water markets, as well as its decentralised tendency. In addition, the attributes of flexibility, predictability and security of tenure, rank CS as one of the best alternative institutional arrangements. However, critical issues like: water rights; water transfers; water markets; and the general administrative control, need some minor institutional amendments if CS is to be adopted in South Africa.

A case study at Vanderkloof dam assumes the existence of CS in which the arrangement provides Ramah Canal irrigation water users exclusive right to allotted reservoir capacity shares as well as inflow shares, in an effort to test the applicability of CS, as well as the benefits it can offer the water user.

A simulation model SIM–DY–SIM was used to determine Marginal Value Products (MVPs) for 75-hectare farm, under two Crop Mix scenarios of cultivating lucern, maize and wheat; potatoes, maize and wheat. The results show that, MVPs (which determine the farmer's ability to pay for water) differ significantly with respect to crop mixes and also across seasons.

The shadow prices (MVPs) were also derived at different water scarcity scenarios to determine the optimal water use policies that the farmer would pursue. The MVPs, indicating the ability to pay in the immediate season or in the future, provide the capacity for determining water prices in both the present and in the future. This characteristic is very vital for trading water rights.

The MVPs also facilitate good water use decision-making since they are linked to the decision to release or save water. The implications of these MVP values for water transfers and trading and hence allocation and efficient use of water becomes apparent.

The other set of results compared the use of SDP derived rules with the alternative of no rules pertaining to the farmer's water supply reliability. It is noted that reservoir capacity and inflow shares, which ultimately determine the farmer's water supply reliability, were better-managed using SDP derived rules than without rules.

Deductions from the SDP simulations from the viewpoint of the usefulness of MVPs to value water, to the advantages of using SDP derived rules to make optimal water use decisions, opens a new frontier for efficient allocation and use of South Africa's water resources.

Keywords: ***Institutional arrangement, Capacity sharing, SIM-DY-SIM, Inflow shares, Capacity shares, Stochastic dynamic programming, Marginal value product, Planning horizon***

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LIST OF ABBREVIATIONS

BC:	BASE CASE
CAN:	*COMISION NACIONAL de AGUA*
CCs:	CATCHMENT COUNCILS
CIS:	COMBINED IRRIGATION SCHEMES
CMAs:	CATCHMENT MANAGEMENT AGENCIES
COAG:	COUNCIL OF AUSTRALIAN GOVERNMENTS
Cs:	CAPACITY SHARES
CS:	CAPACITY SHARING
DCA:	DISCRETIONARY AND CONSENCUS ALLOCATION
DP:	DYNAMIC PROGRAMMING
DWAF:	DEPARTMENT OF WATER AFFAIRS AND FORESTRY
GM:	GROSS MARGIN
IS:	INFLOW SHARES
LMW:	LUCERN MAIZE WHEAT
LP:	LINEAR PROGRAMMING
MOWR:	MINISTRY OF WATER RESOURCES
MVP:	MARGINAL VALUE PRODUCT
NSW:	NEW SOUTH WALES
NWA:	NATIONAL WATER ACT
OCP:	OPTIMAL CONVERGENT POLICY
OFM:	OBJECTIVE FUNCTION MATRIX
PMW:	POTATO MAIZE WHEAT
RDP:	RECONSTRUCTION AND DEVELOPMENT PROGRAMME
SDP:	STOCHASTIC DYNAMIC PROGRAMMING
SIM 1:	SIMULATION 1
SIM II:	SIMULATION 2
TPs:	TRANSITION PROBABILITIES
WACC:	WEIGHTED AVERAGE COST OF CAPITAL
WCC:	WATER CONSERVANCY COMMISSIONS
WMAs:	WATER MANAGEMENT AREAS
WRC:	WATER RESEARCH COMMISION
WRP:	WATER RESOURCE PLANNING (CONSULTING ENGINEERS)
WSA:	WATER SERVICES ACT
WUAs:	WATER USER ASSOCIATIONS

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION AND PROBLEM STATEMENT

The motivation for this study is derived from broad national as well as local perspectives. These two perspectives illuminate the problems to be addressed.

1.1.1 National perspective

South Africa is predominantly arid with rainfall less than the world average unevenly distributed across the country (Department of Water Affairs and Forestry (DWAF), 1997). The development of South Africa's water economy is alleged to have reached a matured phase (Backeberg, 1997), yet water scarcity still persists, thus painting a bleak future. DWAF (1997) revealed that at the present population of approximately 42 million, only 1 200 kilolitres of fresh water is available for each person per annum. The country is thus on the threshold of what is referred to in international circles as "water stress".

The dawn of the new South Africa also poses new challenges and demands on the reallocation and sustainability of water resources as the competition between water users escalates. This calls for immediate action on sustainable development, utilisation of the country's water resources and changes in the institutional arrangements pertaining to property rights structures necessary for the optimal allocation of water. The promulgation of the new National Water Act of 1998 bears testimony to this urgent call. In this new National Water Act, water for human consumption and environmental or ecosystem protection (referred to as reserve) is to receive priority and international obligations must also be satisfied.

The Reconstruction and Development Programme's (RDP) extension of electricity to most rural areas is also likely to exert considerable pressure on hydropower generation. The effect of the above plan on the water resource base becomes apparent.

It is therefore crucial at this stage to allocate and use water optimally. As a matter of necessity, appropriate means must be sought to curb inefficient water use.

The complexity and dynamic nature of this problem requires an integrated and completely new approach that involves all role players in the water industry - the water management approach has to change. According to Backeberg (1997), water management must change from a structural engineering approach of providing water, to an institutional economic approach of balancing demand with supply of water. As a result, focus must be on the adaptation of water institutions to achieve objectives of more efficient and equitable utilisation and reallocation of available water resources.

A vibrant and dynamic water market will also play a positive role in efforts to achieve efficiency regarding the reallocation and use of this scarce resource. However, reliance on market forces *per se* will not ensure sustainable use of the resources unless there is an institutional and legal backing (Nagaraj, 1999).

The National Water Act (Government Gazette No. 19182, 1998) provides a framework for the management of the water resources in South Africa. This framework provides for the establishment of water management institutions, which include Catchment Management Agencies (CMAs) and Water User Associations (WUAs). The core purpose of these institutions is to ensure the sustainable use of water resources in their areas of operation, in line with the aim of the Water Act, which is underpinned by the principles of equity, efficiency, sustainability and representativity (Department of Water Affairs and Forestry, 1999a).

Currently, South Africa is divided into 19 Water Management Areas (WMAs) for the development of the national water resource strategy (see Figure 1.1). The various water management areas are unique regarding the natural resource endowment and the demand posed by the various water use sectors. Each management area therefore has to meet specific needs or requirements. Acknowledging this uniqueness, the Water Act provides a range of options and institutions that could be employed in the establishment of CMAs and which are driven by local needs.

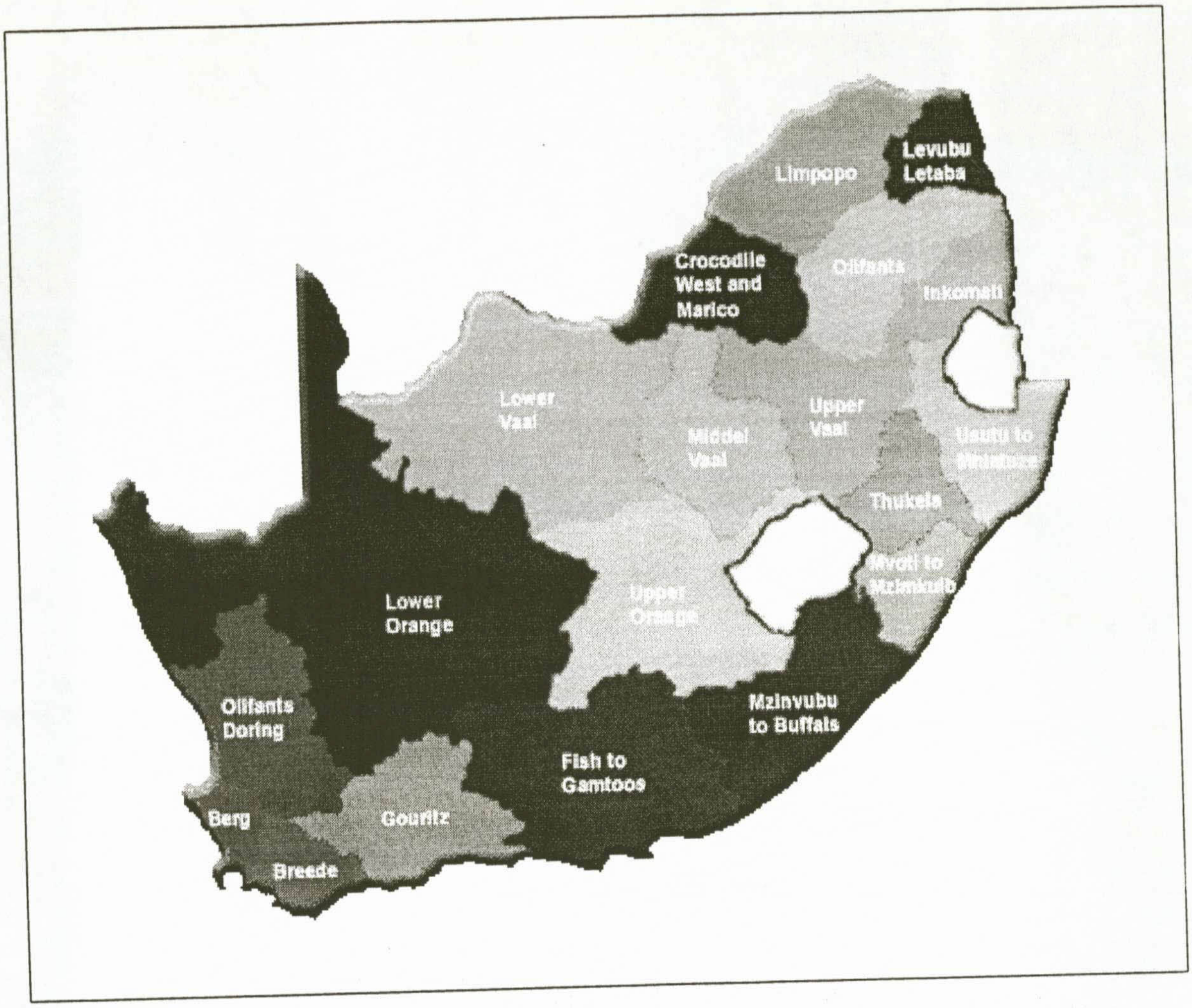


Figure 1.1: **The catchment management areas of South Africa**
(Source: DWAF, 2002)

1.1.2 Area perspective

The issue frequently stressed in motivations for policy change is that water use efficiency should be stepped up by all sectors within the country, especially by the irrigation sector, which uses approximately 42 per cent of the total available water (Backeberg, 1997; Department of Water Affairs and Forestry, 2000b).

In order to manage water resources on local basis and to facilitate transfers within integrated catchments, in order to make it available to them for different users equitably and efficiently, institutions or bodies like CMAs and WUAs require appropriate decision support management systems and tools in the new dispensation to enable them to apply effective water management. These tools may be in the form of computer models for efficient reallocation and use of water, or relevant information that can be applied to good effect in their entire water management activities. Thus far, these aids are lacking and must be put in place.

The Orange River Basin, one of the most important irrigation areas of South Africa and draining about 48 per cent of total runoff (WRC 1996), certainly remains the focus of the socio-economic activity of the entire North-Western part of the country. It is therefore imperative that the economic importance of this river basin should never be compromised and the knowledge vacuum that exists concerning the value of water to irrigation farming and the other water use sectors should not be left unattended to. With evidence of growing competition between water use sectors in the area, especially irrigation and hydropower generation, the likelihood of a water shortage is looming. Water reallocation is therefore becoming an important issue.

To facilitate water reallocation in the area, knowledge of the economic value of water is important. Currently the economic value of water in the Orange River at the Vanderkloof Dam is unknown. This is a serious impediment to the establishment of water markets, and the facilitation of water trading resulting in more efficient reallocation of water. The effectiveness of the new bodies, WUAs and CMAs, to formulate consumer prices and to facilitate the transfer of water between different uses would be hampered. There is an urgent need to resolve this crisis.

Furthermore, as a result of water scarcity, changes to the production practices of farmers are required to ensure that water use levels are in line with optimal water use strategies. This is a dynamic process, which must be investigated continuously in order to maintain the sustainability of water resources.

This study will therefore provide vital information for all water managers and users, especially WUAs and farmers, to manage water effectively. The study will undoubtedly add value to already existing institutional arrangements, as set out in the New Water Act, by alerting or advising policy makers about any possible flaws and providing suggestions for amendments that will refine water management approaches in the country regarding equity, efficient allocation and sustainable use.

1.2 MAIN AIM

The main aim of this research is to evaluate Capacity Sharing (CS) as an alternative institutional arrangement and determine its applicability to South Africa. The ultimate aim is to adopt the Australian water allocation simulation model to determine the capacity share of irrigated farmers and hence the value of water in the Orange River.

1.3 RESEARCH AREA

Figure 1.2 provides the orientation map for the study area. The Orange River catchment between Gariep and Vanderkloof Dams (Figure 1.3) will be used in the generation of the hydrological data for Vanderkloof Dam, which is the focus of the study. Irrigation farmers involved in this study are located downstream of Vanderkloof Dam along the Ramah Canal, as shown in Figure 1.4. The study is limited to Ramah Canal, as all farmers along the canal extract water from the facility, which was built exclusively to serve irrigation needs. This arrangement is considered valuable and most suitable for Capacity Sharing modelling procedures. Thus the Orange Riet Canal, which is also on the Vanderkloof Dam main canal, is excluded from the study.

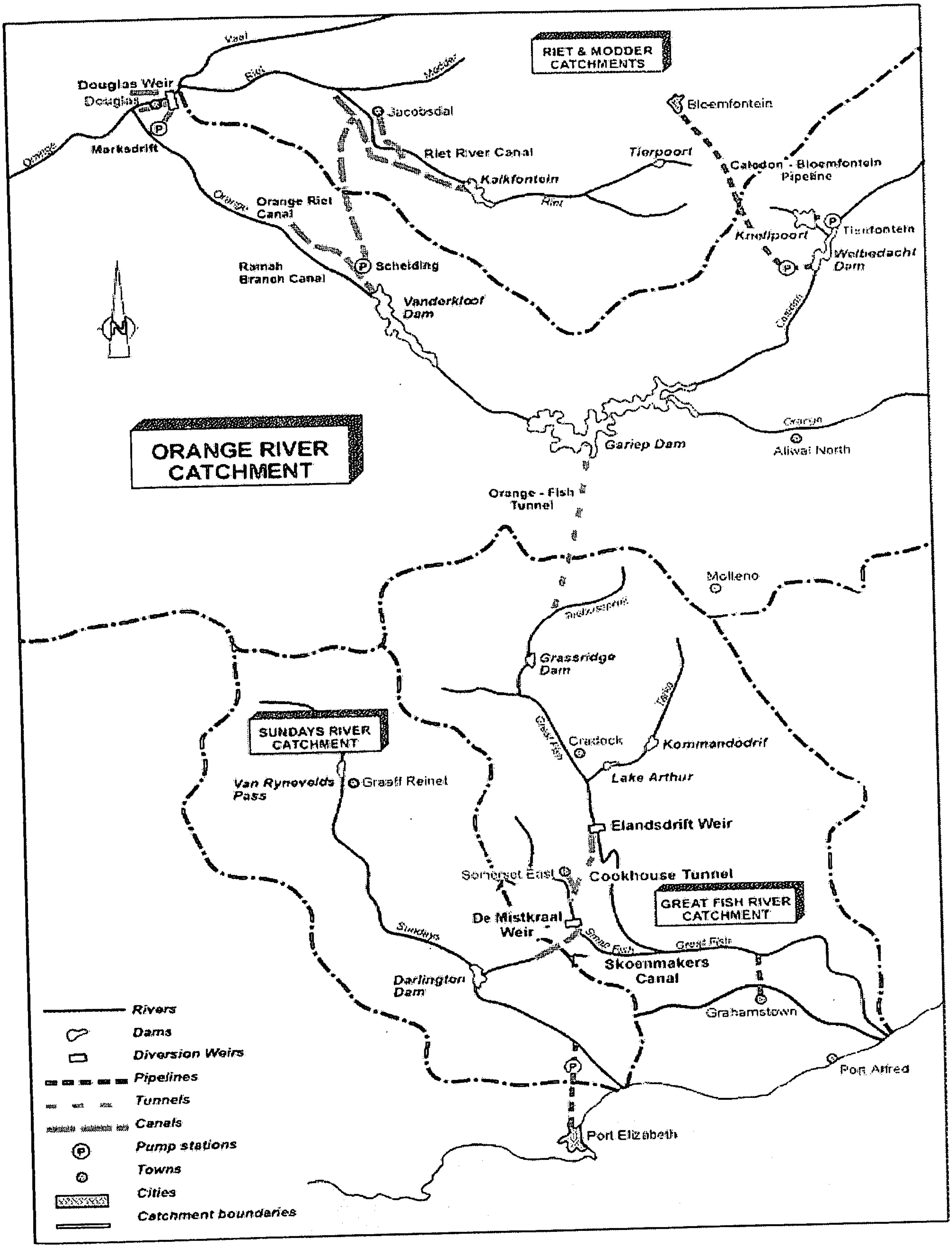


Figure 1.2: Orientation Map of Study area
Source: Water Resource Planning (WRP), 2001

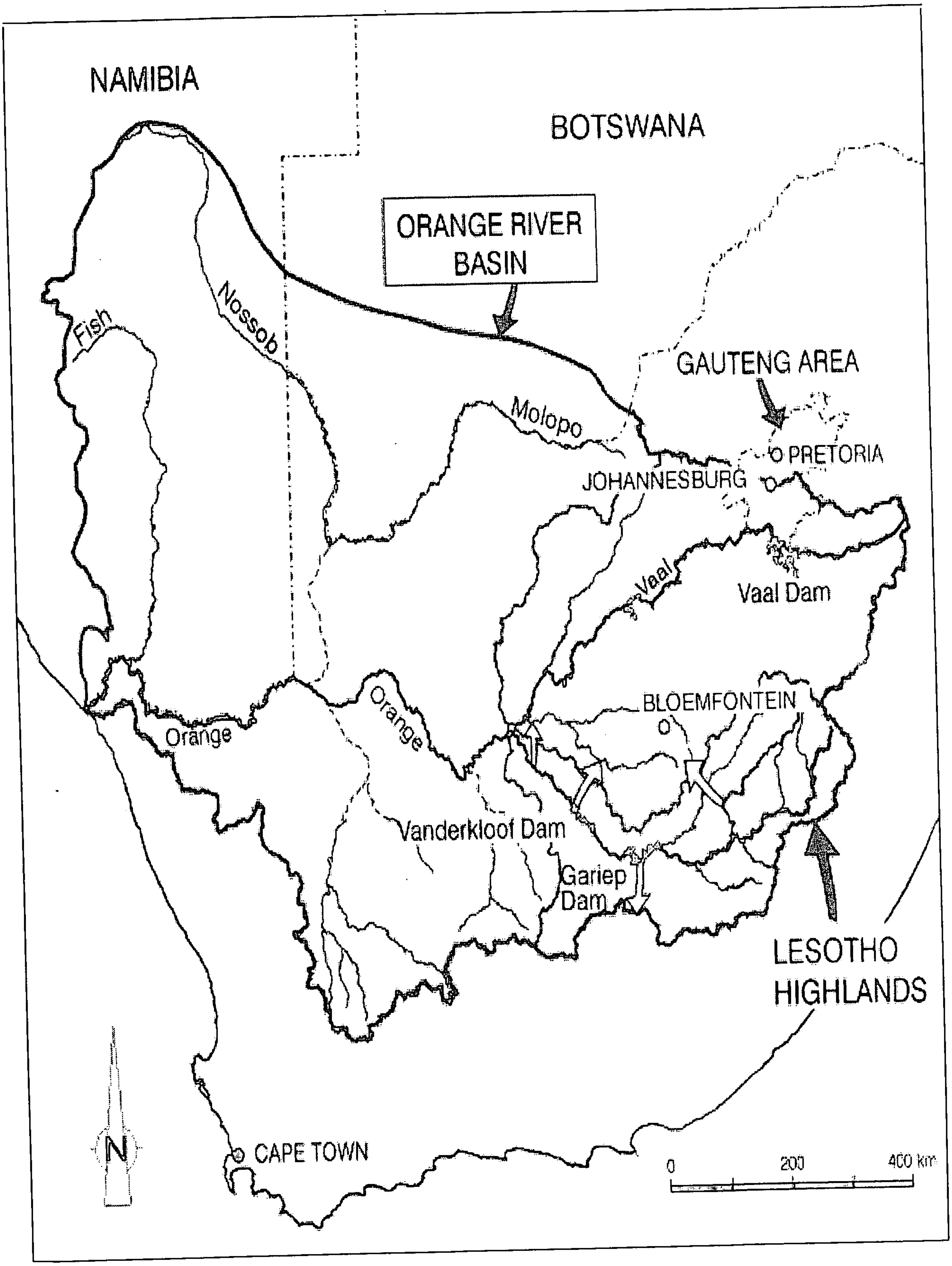


Figure 1.3: **The Orange River catchment showing Vanderkloof and Gariep Dams**

Source: Water Resource Planning (WRP), 2001

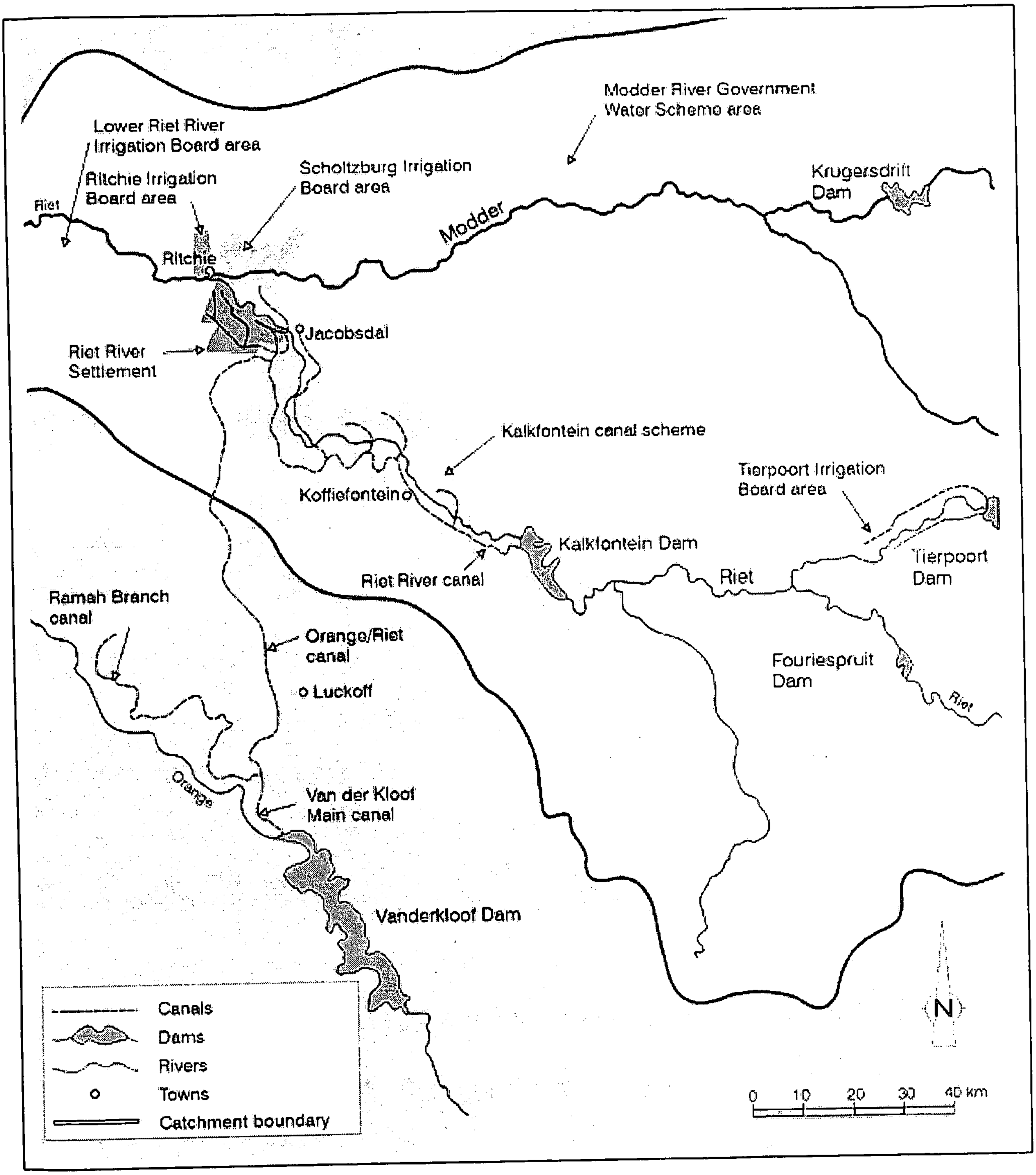


Figure 1.4: The Middle Orange River Catchment showing Ramah Canal farming areas and former irrigation boards.

Source: Water Resource Planning (WRP), 2001

1.4 STRUCTURE OF THE THESIS

This thesis consists of seven chapters. The first chapter forms the introduction and discusses the motivation; problem statement and the study area. Chapter 2 discusses the theoretical framework and outlines the methodology for the entire study. The third chapter evaluates alternative institutional arrangements for South Africa by drawing on international institutional trends. In Chapter 4, an institutional arrangement known as capacity sharing will be evaluated for its suitability and applicability in South Africa. Stochastic Dynamic Programming (SDP) model on which Capacity Sharing model pivots will be discussed in Chapter 5. Empirical results of the SDP model and water management procedures for various water scarcity scenarios are discussed in Chapter 6. The last Chapter is the conclusion and recommendations for further research.

CHAPTER 2

THEORETICAL AND METHODOLOGICAL FRAMEWORK

2.1 INTRODUCTION

In order to avert a threatening water scarcity scenario in South Africa, as explained in Chapter 1, the following factors, among others, have to be investigated constantly to empower water managers to adequately allocate and promote judicious and efficient use of the scarce water resources:

- Value of water as a resource;
- Natural availability; and
- Use patterns.

. This chapter considers a theory of thought and a methodology that may be useful to address some of the factors that challenge South Africa's water security. Firstly the concepts that will be encountered in the study are explained.

2.2 CONCEPTS

2.2.1 Economic efficiency

Economic efficiency refers to a condition that is achieved when resources are used over a given period of time in such a way as to make it impossible to increase the welfare of any person without harming others (Department of Water Affairs and Forestry, 1999b).

2.2.2 Equity

Efficient resource reallocation that allow access and benefits to be derived by both old and emerging users of the resource, either within a sector or between sectors. The allocation process should be perceived as providing equal opportunities for all prospective resource users (WRC, 1996).

2.2.3 Social equity

Social equity requires resource allocation to occur mainly through administrative devices with the purpose of serving social justice and equality requirements. In the context of water resources, social equity implies that all the basic water user groups have fair and reasonable access to the nation's water resources. Allocation of water resources under social equity must facilitate universal and affordable access to basic water supply (Department of Water Affairs and Forestry, 1999b).

2.2.4 Transaction costs

According to Dahlman (1979), transaction costs are the costs of specifying and enforcing contracts that underlie exchange pertaining to:

- information search;
- bargaining and decision making;
- policing and enforcement; and
- risk and uncertainty associated with transfer of rights due to imperfect information.

2.2.5 Institutional arrangement

An institutional arrangement determines the basis for administrative control over resources (in this case water). It comprises administrative, legal and economic systems within which water management must operate. It is capable of creating order and certainty for users to facilitate the achievement of economic and social goals, but can equally create impediments to efficient resource use (Backeberg, 1995; Livingston, 1995; North, 1990)

2.2.6 Marginal value product (MVP)

Marginal value product (MVP) refers to the amount that a farmer can afford to pay for an additional unit of an input e.g. water. In other words MVP is the shadow price.

2.2.7 Marginal revenue

Marginal revenue for the n^{th} unit of output is, according to Merrett 1997, defined as the difference in total sales income derived from selling *n* rather than $(n - 1)$ units.

2.2.8 Dynamic programming (DP)

Dynamic programming is an optimisation technique which was developed almost half a century ago and that has proved useful for addressing a variety of practical problems. The term "dynamic programming" was coined by Bellman in 1957 to describe the mathematical theory of a multi-stage decision process. Any physical system through the course of time is subject to change, meaning that the variables within the system undergo transformation. The decision process in dynamic programming is, according to Bellman (1957), described as the case offering a choice regarding transformations that may be applied to the system at any time.

The common practice in all dynamic programming models is to express the decision problem by means of a recursive formula. In very simple terms the recursive formula is (Hornbaker, 1985):

$$f_n(s) = \text{Max}\,[\,R_{sj} + f_{n-1}(j)]\quad n = 1,2,\ldots\ldots\ldots N \qquad \ldots\ldots \text{ Equation (2.1)}$$

Where $f_n(s)$ = maximum return when in state *s* with *n* more stages to go.

R_{sj} = the returns associated with moving from state s to state *j*.

In dynamic programming each decision may be thought of as a choice of a certain number of variables, which determine the transformation to be employed; each sequence of choices or policy is a choice of a larger set of variables. By lumping all the choices together, the problem is reduced to a classical one of determining the maximum of a given function (Bellman, 1957).

To facilitate understanding of the concepts that follow, the parameters *i, j, k* and *n* are defined first.

i = state at the beginning of time

j = state at the end of a specified time

k = decision taken

n = time, e.g. number of years left in a planning horizon

The recurrence relationship used in this study is found in Chapter 5, where these concepts and parameters are defined further to reflect their meaning in the model.

2.2.9 Stochastic dynamic programming (SDP)

Dynamic programming may be deterministic or stochastic. That means, given the current state i and a decision k, the state j at the end of the current stage as well as the return associated with the transition are known. In other words, the result of a decision was known with precision before it was taken, hence deterministic (Dudley, 1998). However, dynamic elements existing in many real world problems make it impossible to predict outcomes prior to taking the decisions. Outcomes or results are therefore stochastic in nature. Unlike deterministic dynamic programming, where state-variable transitions for each decision are known with certainty, stochastic dynamic programming can have multiple outcomes or transitions resulting from a given decision with probabilities of all such outcomes attached to each outcome (Dudley, 1998).

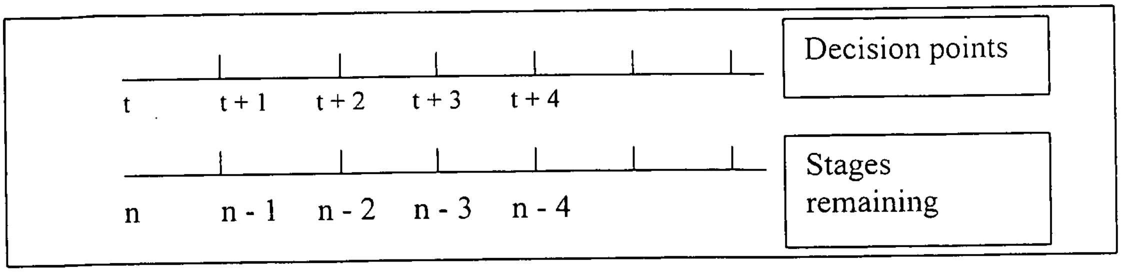
2.2.10 State of a system

The state of a system refers to the characteristics or conditions of the system at a point in time or stage (Dudley, 1998). System as used here means the reservoir storage space, in which case state refers to the level of water in the reservoir. The parameter, which quantifies the condition of the system at any time that a decision is made, can be referred to as a state variable.

2.2.11 Planning horizon and stages

The length of time over which one is concerned with the behaviour of a particular system characterises the planning horizon (Dudley, 1998). Usually this is a finite length of time. Planning horizon and stage are interrelated. Table 2.1 distinguishes between the two terminologies.

Table 2.1: The concepts of planning horizon and stages.



Source: Dudley, 1998

In Table 2.1 decision points can be numbered from the present time *t* to say *t+4*, considering a situation of say four periods remaining in a planning horizon. In order to determine the optimal sequence of decisions by backward-recursion under dynamic programming, these periods must be renumbered to indicate the number remaining in the planning horizon. By convention the numbers remaining in the planning horizon are referred to as stages. As in Table 2.1 the stage variable *n* refers to the number of stages remaining in the planning horizon at decision point *t*; at time *t +1* the number of stages remaining becomes *n-1*.

2.2.12 Transition probability

This refers to the probability of moving from state *i* to state *j* under decision *k* in stage *n* and symbolically represented as $P_n(i,j,k)$ (Dudley, 1998).

2.2.13 Immediate returns

The contribution to the objective given by following a decision over the immediate stage is referred to as immediate return. If the objective is to maximise net revenue, the immediate return would be the net revenue from the immediate stage. If the objective is to minimise costs, the immediate return would be the cost from the immediate stage. An immediate return is therefore a function of the state and decision in a particular stage and according to Dudley (1998), may be written as

V_n (i,k) where V_n is the immediate return function in stage n

2.2.14 Optimal remaining returns

For a given state and stage, an optimal plan or policy will result in optimising the sum of returns over the remaining stages. This optimal sum is referred to as the optimal remaining returns (Dudley, 1998). Other terms used include "optimal value of state", "optimal value of the objective function" and "optimal value of the criterion function" (Bellman, 1957). Regardless of the name used, it is commonly represented by the equation

f_n (i).

2.2.15 Optimal policy

The uniqueness of dynamic programming as an optimisation technique lies in the principle of optimality. According to Bellman (1957), "*an optimal policy has the property that, whatever the initial state and initial decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision*". An optimal plan or policy is therefore a sequence of best decisions for the remainder of the planning horizon in accordance with a given objective, given the current state and stage.

2.2.16 Discount rate

The discount rate used in this study refers to the time preference rate that will indicate the water user's (farmer) preference for income now rather than later. Gilpin (1999) enumerated five schools of thought pertaining to the rules that must be used in determining discount rate. He argued that a discount rate must reflect the interest of future as well as present generations.

A popular approach used for determining the rate of return or the discounting rate involves calculating the weighted average cost of capital (WACC) (Standard Bank, 1988). Meiring and Oosthuizen (1991) determined the discount rate for three farmer categories and found rates to range between 12,34 and 14,03 per cent. For water users in this study, the determination of discount rates is similar in approach (see Table 5.1 for details).

2.3 THEORETICAL FRAMEWORK

The theoretical framework for this study is based on two major issues, as reflected in Figure 2.1. Institutional issues are tackled first with emphasis on water law, water policy and water administration being the main components of water institutions. The second section deals with the role of optimisation techniques and simulation models as tools for addressing pertinent issues emanating from water institutions.

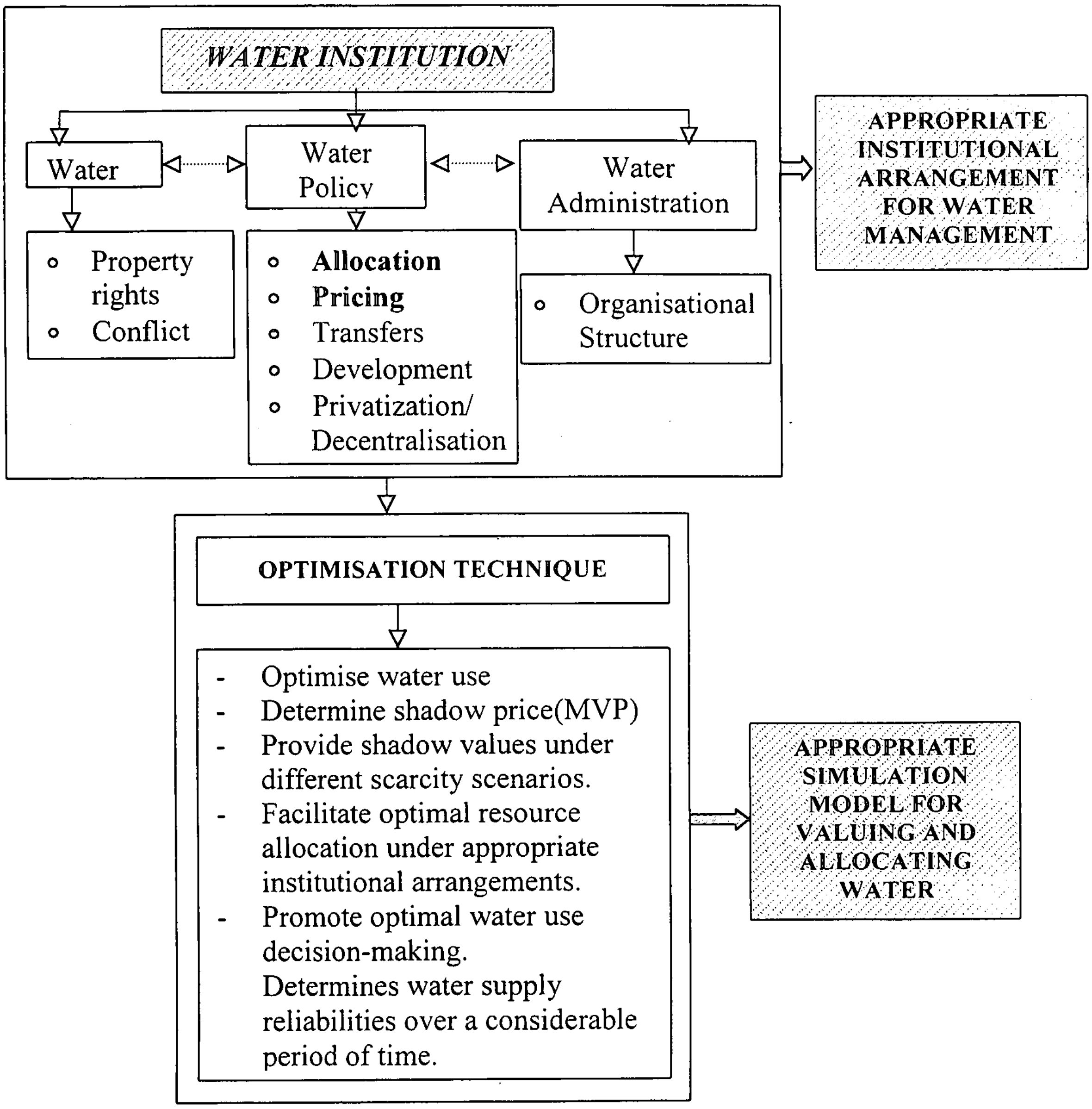


Figure 2.1: Illustration of the theoretical framework for allocating and valuing water.

Institutional arrangements determine the basis for administrative or market control over water and are capable of creating order and certainty for users to facilitate the achievement of economic as well as social goals. On the other hand, institutional arrangements create impediments to efficient resource use, requiring that individuals expend significant amounts of resources to compensate for their outdated designs (Livingston, 1995). The assertion of North (1990) that men live in a world of apparent rapidity in institutional change cannot be overruled. Competition resulting from the continuous interaction between institutions and individuals within organisations in the economic setting of scarcity is the key to institutional change. Changes in the technology whereby property rights are defined and enforced can also alter institutions (Anderson and Snyder, 1997). However, the path of institutional change that determines the evolution of an economy is shaped by constraints derived from the past and from the choices of individuals, which continually modify these constraints (North, 1989).

Water laws in South Africa, like in other nations, evolve according to the changes set in motion by social, economic and political developments. Features of the water laws prior to 1956 were mainly riparian (Rowlston, Barta and Mokonyane, 2000; Backeberg, 1994). Post World War II industrial development in South Africa required water legislation to be adjusted, giving rise to the 1956 Water Act. The Act consolidated control, conservation and use of water for domestic, agriculture, urban and industrial purposes. This Act perpetuated the riparian principle in terms of "normal" flow and "private" water, which granted exclusive use but not ownership (Government Gazette No 5718, 1956). The state played a major role in planning and implementing water resource developments. Virtually all aspects of water management were controlled centrally, with full powers vested in the minister. Furthermore, during this era legislation and management policies regarding water resources management and service provision historically favoured only specific water use sectors and population groups. Economic and development goals took precedence over environmental and social goals, seriously compromising general welfare.

The 1998 Water Act of South Africa made fundamental changes in approach to water management. This was dictated by the new Constitution, which was structured to create a more just and equitable society. In summary, the new Water Act stressed the need for equitable allocation, efficient and sustainable use of water resources (see Government Gazette No.19182, 1998)

From a theoretical viewpoint, water pricing is the main instrument that helps to distribute as well as allocate water to users, because it provides appropriate signals and incentives (Montginoul and Strosser, 1997). In general economic terms, prices are set by demand and supply. When an equilibrium price is attained, benefits to society are maximised since marginal increase in benefits equals marginal cost (Perry, Rock and Seckler, 1997). This price is however theoretical, as explained by the cobweb model (Tietenberg, 1996) but unachievable practically because of market distortions. Due to this problem, alternative methods like opportunity cost pricing and shadow pricing have to be used in pricing water resources.

Allocation of resources must generally satisfy Pareto optimal criteria if society is to derive maximum benefit. Where sub-optimal allocations occur, reallocations are necessary. Theoretically, allocations that fail to maximise net benefits forgo the opportunity to make some people better off without hurting others (Tietenberg, 1996).

According to Easter and Tsur (1995), shadow values among uses promote reallocations. The need to measure shadow values is therefore essential. LP and DP methods as optimising techniques can be utilised to good effect in determining shadow values. These two techniques will be discussed in the methodology.

2.4 METHODOLOGICAL FRAMEWORK

The prerequisite for the achievement of optimum allocation, efficient and sustainable use of water resources, is an appropriate institutional framework. This must be followed by appropriate optimisation techniques in water allocation and use. The procedure for this study is therefore divided according to the above-mentioned two categories. Figure 2.2 illustrates the methodology for optimisation and modelling techniques used in this study.

The second category will address water allocation and pricing. This section will encompass optimisation techniques that are used to allocate and value water as a scarce resource. Since the basic methodologies for estimating water values are crop budget analyses and water production function analyses using linear programming (LP) as a tool, LP analyses (Gibbons, 1986) can be used to estimate marginal values of irrigation water on representative farms. Water supply will be varied and LP solutions found for each quantity of water available to the farm, keeping all other constraints constant.

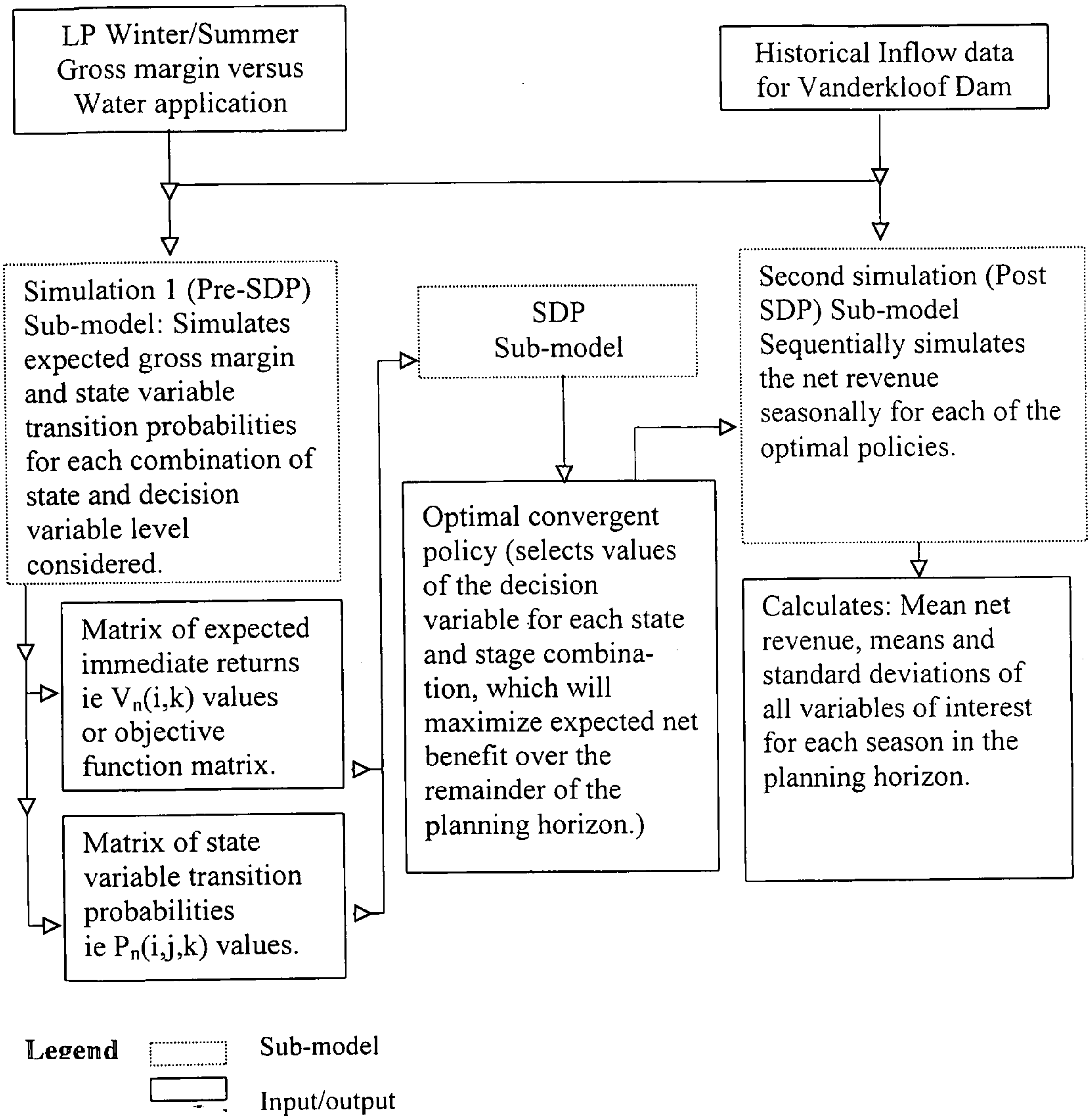


Figure 2.2: Illustration of the interaction between LP input, SIM-DY-SIM model and outputs.

Source: Adapted from Dudley (1999)

When water supply is low the programme solution will allocate water to its highest-valued uses. Consequently, as supply increases, other less valuable or more water-intense crops will enter production and the marginal value of additional units of water will fall. The set of shadow prices derived at various levels of water supply will thus constitute a water demand schedule for the farm. This approach is useful for estimating the value of irrigation water on a short-term basis. For situations where medium to long-term values must be estimated, dynamic programming techniques can be used as in (Dudley, 1988)

LP and DP will therefore form the dominant tools for modelling optimal water allocation and pricing. The modelling section of the study will commence with the compilation of LP matrices for both winter and summer activities separately for three identified farmer groups in the study area. Each of the LPs will be run parametrically (that is changing the availability of water for the farm operation) to determine gross margins (GM) as a function of seasonal reservoir releases by the farmer to his farm. The derivative of this function would provide shadow prices for marginal units of water delivered to that farm for the current season. The LPs would equally determine the best short-run decisions about optimal crop combinations.

The LP runs will be followed by the adoption and execution of a DP model. The model will require a season-by-season GM expressed as a function of water deliveries to the farm. These functions originate from the earlier parametrically run LP models. The model will also require seasonal water inflows into the Vanderkloof Dam based on available historical data. Water Resource Planning (WRP) Consulting Engineers will be co-opted to assist is in the generation of the data. Using their Computer Models, the relevant hydrological information will be obtained.

Firstly, the DP model will be operated to optimise the seasonal releases to the farm, depending on the season and contents of the farm's reservoir capacity share. Secondly, the reservoir capacity share size will be reduced by different percentages to simulate different scarcity scenarios and the consequent best management response. The set of shadow values for water will indicate costs of shortages to the farm and determine the farmer's best management responses. The same LP result and SDP model will be used for this further investigation. Finally, the inflows to the capacity share will be reduced through time to show costs and farmer reactions to reduced probability of water supply. Again the LP-derived functional relation between deliveries to the farm and gross margins will be used. Detailed execution of the model illustrated in Figure 2.2 is discussed exhaustively in Chapter 5.

2.5 RESEARCH PROCEDURE

To achieve the main aim of this study as specified in Section 1.2 of Chapter 1, the following objectives have to be addressed.

2.5.1 Objective No 1: To evaluate institutions and legislation for effective water resource management

This evaluation will determine whether the appropriate institutional provision is in place for water resources in South Africa to be managed effectively and efficiently. Institutional factors which constitute the "rules of the game" (Backeberg, 1995) may aggravate or alleviate water problems. Concerted efforts must therefore be directed at seeking the appropriate institutional provisions that will champion the dreams of attaining water security in the long term.

Activity:

This basically involves a comprehensive study of the South African water institutions to assess the adequacy of the current institutional arrangement in meeting national as well as socio-economic objectives. In the study, discussion will be restricted to the classes of institutions that will shape the allocation of water in South Africa in general and which will influence critically the extent of market-type transfers, if possible. Institutions to be considered are water use rights, water markets, pricing and allocation rules and Water Management authorities. Furthermore, an ideal water institutional framework will be formulated and used to evaluate the South African water institutions. Focus will be on types of decision mechanisms and models involved in water distribution, as well as provisions that must be made to accommodate water markets and ownership rights.

2.5.2 Objective No 2: To evaluate capacity sharing as an alternative institutional arrangement

In a search for appropriate institutional arrangements that will guarantee optimal allocation and use of water efficiently on sustainable basis, alternative institution arrangements must be studied. Capacity sharing (CS) with a potential to guarantee optimal water allocation and efficient use is thus chosen for in-depth study and evaluation.

Activity:

In this evaluation, CS will be studied in general terms to determine whether it is a viable option for augmenting the present South Africa water institutional provisions. Specifically, efforts will be directed at determining whether the institutional form of CS is compatible with the New South African Water Act.

2.5.3 Objective No 3: To determine the short run Marginal Value of water for farmers served by the Vanderkloof Dam's Ramah Canal along the Orange River

Activity:

A survey will be conducted to gather data from farmers on finances, cropping patterns, land use and any other relevant data required for running a linear programme. An LP matrix for representative farmer groups will then be developed. Seasonal gross margins will be determined at various water application levels from which short term MVPs will be determined, as explained in Section 2.4.

2.5.4 Objective No 4: To determine marginal value of water as well as optimal water use policy for farmers along the Ramah Canal using the SIM-DY-SIM water allocation model adopted from Australia.

Natural availability, precipitation and the hydrological conditions of a river system are of paramount importance in water resource management. Sometimes, these factors are considered deterministic where the climatic variables and inflows to the river system are known. But more often than not, they are stochastic, hence necessitating constant study and modelling procedures in order to promote and guarantee water supply reliability to water users. It is worth noting that determining the true value of water as a resource must take scarcity into account. As this factor can only be spelt out by hydrological data, it is imperative that all water value estimates integrate hydrological information.

Activity:

Seasonal hydrological inflows into Vanderkloof Dam will be compiled and used with the gross margins derived from the LP output to run a pre-dynamic programming simulation. A dynamic programme and finally a post-dynamic programming simulation will then be conducted. The simulations mentioned were highlighted in Section 2.4 and will be discussed more in detail in Chapter 5.

CHAPTER 3

INSTITUTIONAL ARRANGEMENTS

3.1 INTRODUCTION

Scarcity is characteristic of most natural resources, and water is no exception. This undeniable fact is a matter of concern for most nations or regions, particularly those that are prone to acute water shortages. In the past few years water crises arose in many countries around the world, countries where water was once abundant. Today 31 countries, accounting for less than 8 per cent of the world's population, face chronic fresh water shortages. By the year 2025, 48 countries are expected to face shortages, affecting more than 2.8 billion people or 35 per cent of the world's projected population (Population Reports, 2001).

Nations are therefore becoming more and more vulnerable to acute water shortages. In this chapter the first matter to be discussed is the factors that account for a nation or a region's vulnerability to water shortage. This chapter highlights the institutional arrangements of a spectrum of water economies internationally, exhibiting a variety of political agendas, laws and resource realities. It will also develop a theoretical efficient water management institutional framework based on the theory and principles of institutional change. Using this framework and lessons from international water institutional arrangements, the efficiency of the new institutional arrangements provided to manage South Africa's water resources will be evaluated.

3.1.1 Vulnerability of water resources

A region becomes vulnerable to water resource scarcity if it cannot sustain economic and social activities simultaneously with the stated goals of economic activity (Kulshreshtha, 1993). Vulnerability can be attributed to several related factors as shown in Figure 3.1.

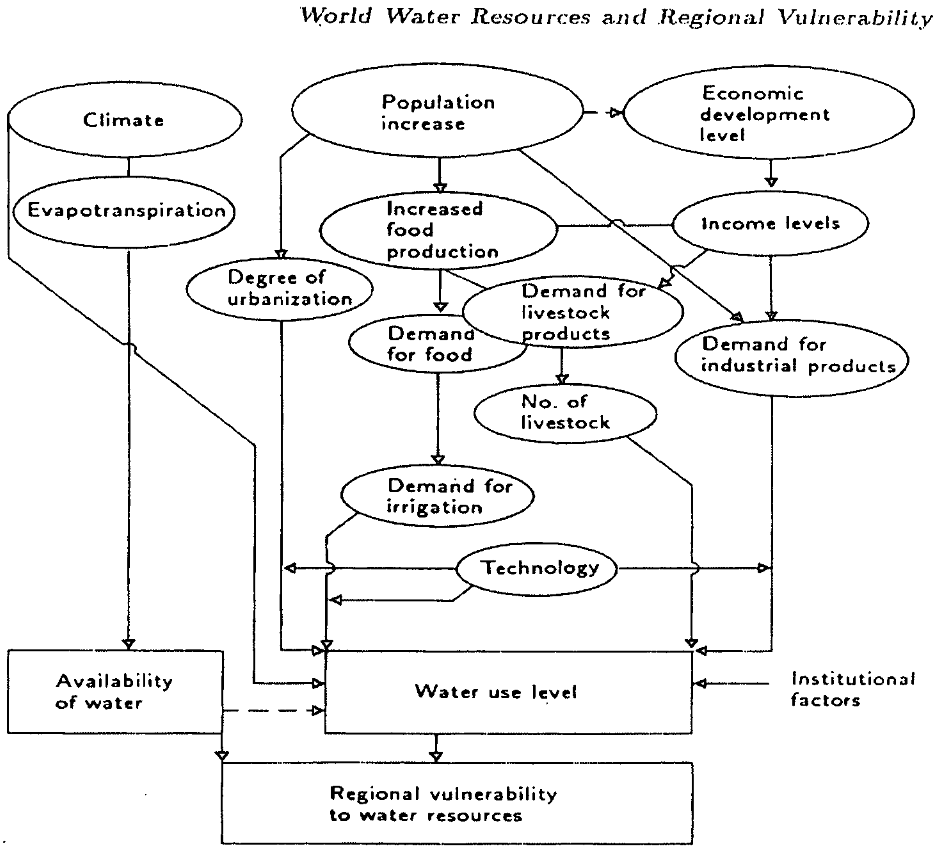


Figure 3.1: Factors determining a region's water resource vulnerability.
(Source: Kulshreshtha, 1993)

It is evident that a nation's increasing vulnerability to scarce water resources may be determined through three major types of change, namely changes in population, changes in level of economic activity and global climatic changes. Increase in population implies the need for stepping up food production due to higher demand for food, livestock and livestock products. This is likely to mean higher demand for irrigation. Population increases also impact on economic development and demand for industrial products as income levels change. All these factors together determine water use levels. Climatic changes set the natural limit for water availability and determines water use levels. Institutional factors, quantity of water available and water use levels consequently determine a region's vulnerability to water resources. Therefore, to avoid water stress or a full-blown shortage situation, efforts must be directed to keeping water use levels in line with the amount available. The role of institutional factors in this effort becomes clear.

3.1.2 Institutional factors

Institutional factors contribute a great deal to most water problems and institutional changes often play a significant role in finding solutions to these problems. According to Frederick (1986), institutional factors often restrict transfers among uses, limit incentives for efficient use and where water rights in particular are clouded in uncertainty; a nation's development is likely to suffer.

Thus, in addition to the state of resource endowments, the root of the concern regarding future water shortages lies in the laws, administrative practices and other institutions that create uncertainty with regard to water rights, pose obstacles to the development of new supplies or reallocation of existing supplies to new uses, as well as providing little incentive for conservation (Frederick, 1986). In order to sustain a country's economic and social activities with regard water resources, unquestionable institutional arrangements to guarantee efficient and optimal use must be in place.

3.2 THE THEORY AND PRINCIPLES OF INSTITUTIONAL ARRANGEMENTS

To evaluate the effectiveness of water institutions, particularly those emerging from a new dispensation like that in South Africa, it is imperative to, firstly, study institutional economics theory, after which a theoretical efficient water institutional framework can be developed to form the basis for evaluation.

3.2.1 Methodological framework of Sustainable Water Institutions

An institution is described as a type of infrastructure that facilitates or hinders human co-ordination and the allocation of resources. Institutions simplify action choices and are not separate from, but part of, the individual (inter) actions. Thus, institutions not only define and delimit the set of actions available to individuals, they are simultaneously shaped by individuals and make individual interactions possible (Sjostrand, 1995). Institutional changes are, according to North (1990), consequences of changes in rules, informal constraints and the effectiveness of enforcement procedures.

Institutional frameworks for water management theoretically revolve around burning issues regarding, among other things; property rights, water markets, water transfers, transaction costs, information, allocation of resources, pricing and general efficiency of resource use (Eggertsson, 1990; North, 1990; Allen, 1998; Dinar and Loehman, 1995). The point of convergence for all these issues is welfare. For instance, from a welfare maximisation viewpoint in institutional economics, no changes in property rights are justifiable except those resulting from voluntary exchange and those who lose valuable rights need to receive full compensation for their losses. Also, within a set of all possible rule structures that maximise wealth, the optimal set of rules should be the one that diverts resources into uses that generate the most wealth.

Alternatively, rules are optimal when resources are in their most valued use (Eggertsson, 1990). To consider optimal allocation of water resources in a broader perspective, welfare economic principles must therefore be borne in mind, since economic efficiency also has welfare implications. According to the Pareto optimality criterion, any changes that make at least one individual better off and no one worse off is an improvement in social welfare. Conversely a change that makes no one better off and at least one worse off is a decrease in social welfare (Koutsoyiannis, 1979).

With the focus of microeconomic theory being economic efficiency, the importance of efficiency as it relates to social welfare requires attention. According to the traditional neoclassical economics definition of efficiency, a resource is used efficiently when it has been allocated to the user who has the highest value for it as measured by the user's willingness and ability to pay (Eggertsson, 1990).

In welfare economics, efficiency is a necessary prerequisite for the maximisation of welfare, however, it is not sufficient to guarantee the maximisation of social welfare

(Koutsoyiannis, 1979). Pareto efficiency is reached when all transactions that are mutually advantageous have been completed. The first welfare theorem clearly establishes that only for certain mathematical restrictions can competitive markets achieve Pareto efficiency. Varian (1990) states that efficient market outcomes are recognised to depend on the initial distribution of endowments. That implies that a given distribution of endowments will give rise to one set of market outcomes, while a different distribution gives rise to a different set of outcomes with both sets considered Pareto efficient. Based on the above arguments, an efficient and effective institutional arrangement for water use, must therefore have property rights, water transfers, pricing and allocation mechanisms, among others, structured in a way that makes at least one water user better off and none worse off.

3.2.2 Property rights

A prerequisite to an efficient and effective water market is that water rights are well defined and non-attenuated to satisfy the ideal conditions for efficient market performance leading to an efficient water allocation. (Eggertson, 1990; Saliba and Bush 1987; Backeberg, 1996). A property right system, which is not well defined, is characterised by high transaction costs and high transaction costs are known to be a serious hindrance to exchange processes (Bonti-Ankomah and Fox, 2000). The structure of property rights will certainly affect individual behaviour in one way or the other. Economic theory suggests that any restriction on private property dampens the spirit of long-term investment (Eggertson, 1990). For instance, when exclusive ownership rights to water use by individual farmers are restricted and long-term leases not allowed, farmers are unlikely to allocate resources to various potentially lucrative investment projects, since their rights to yields accruing in future periods are uncertain. Thus a prerequisite for efficient water allocation will imply that:

- Water rights are clearly defined,
- Water rights must be enforceable to ensure that the owner can reap the benefits of ownership,
- Water rights must be transferable to ensure that owners consider and take advantage of the opportunity cost of water.

In the case of water, this would involve clarifying the rights of individuals and groups in many cases. A clear and equitable initial distribution of water rights is required to prevent markets incurring opposition for appropriating certain groups' rights. It is therefore essential that the process of establishing water rights take into account not only formal legal rights, but also perceptions of water rights, including rights to return flows (Meinzen-Dick and Rosegrant, 1997).

3.2.3 Water markets

Tradability of water rights is an idea that is gaining popularity worldwide. The idea of trading water rights is not new but the host of ideas explaining its effects and supporting its implementation is quite new. A competitive market has been characterised as a mechanism for non-controversial resolution of allocation problems, with buyers and sellers presented with a range of choices in a setting that is neither compulsory nor confrontational (Howe and Goodman, 1995). Water markets are allocation mechanisms based on an initial allocation of water rights. Based on the confrontation between water supply and water demand, water is (re-) allocated between users at an equilibrium price established in the market. Unlike most markets, water traders have also a direct utility in using water on their own farms or property. Thus, they compare the marginal value product of water on their farms or property with the expected equilibrium price prior to their decision whether to participate in water transfers (Montginoul and Strosser, 1997).

An efficient water market therefore requires water rights that are well defined in the unit of measurement and reliability of the right; enforceable, transferable and ideally separate from land use. In addition, an efficient administrative system that prevents abuse of the system and maintains proper claim of title over the water rights must be instituted (Armitage and Nieuwoudt, 1998). The other requirements for water markets to function include water scarcity, large numbers of purchasers and sellers, or limited transaction costs and the existence of an appropriate information system (Montginoul and Strosser, 1997).

Despite the potential problems with water markets, such as high transaction costs, variable nature of water as a resource and externalities such as pollution, water-logging, and other adverse and often irreversible environmental effects which are normally imposed on third-parties, it is an important facilitator for the optimal reallocation of water resources (Meinzen-Dick and Rosegrant, 1997). Louw and Van Schalkwyk (1997), emphasise that, if water markets are given the chance to operate, Pareto optimality will be reached and the general welfare of the nation will increase as farmers will resort to planting crops with a higher value.

3.2.4 Water transfers

Transfer procedures related to property rights need to be defined, according to Randall (1981). Implementing water transfer transactions requires conveyance networks to facilitate the transfer between districts at reasonable cost. The public agency's responsibility will therefore be to generate the physical infrastructure, define water endowments, define rules for trading endowments and rights, and maintain institutions to monitor and enforce these rules (Easter and Tsur, 1995).

A central water authority may be limited in its ability to reallocate water between sectors and districts. It is therefore natural to allow districts to trade water among themselves to correct inappropriate initial allocations of the central authority. Allocations to the water district from the central agency can be perceived as setting water endowments. Districts, having their endowments are free to trade among themselves improve the well-being of their members. Such voluntary transfers can improve the buyers' and sellers' welfare (Easter and Tsur, 1995)

3.2.5 Transaction costs

Transaction costs are the costs of establishing and maintaining property rights. If transaction costs are prohibitively high, property rights will be neither established nor maintained, meaning property rights will be zero. If high transaction costs make allocations through the market a costly solution, the state can choose among several forms of intervention to guide resources to their highest value uses. One approach is to allocate exclusive rights directly (Eggertsson, 1990).

According to Meinzen-Dick and Rosegrant (1997), in the real world transaction costs are rarely equal to zero. Costs typically associated with market exchange in the form of information gathering, physical conveyance losses, monitoring and enforcement costs could exceed the benefits to be earned from trade substantially. Simulations with different values of transaction costs confirmed that high transaction costs weakened the overall case for water markets considerably (Shah and Zilberman, 1995). However Gazmuri and Rosegrant (1994) argue that where the difference in value of output per unit of water is high, markets in tradable water rights could still lead to considerable efficiency gains and benefits great enough to offset the transaction costs.

3.2.6 Information

A vast array of information regarding various activities that are involved in the swift and efficient exchange of property rights is needed. When this information is costly, the activities related to the exchange between individuals give rise to transaction costs (Eggertsson, 1990). According to Eggertsson (1990) the activities include:

- the search for information about the distribution of price and quality of the commodity, including the search for potential buyers and sellers and their behaviour and circumstances;
- closing of contracts;
- monitoring of contractual partners to see whether they abide by the terms of the contract;
- the enforcement of contracts and the collection of damages by defaulters; and
- the protection of property rights against third-party encroachment;

Thus in a full information economy where there are no transaction costs, economic outcomes are known in advance and contracts are fully enforced. However in a world of uncertainty, costly measurement and incomplete enforcement predominate. In addition, economic outcomes may vary depending on the type of contract chosen to organise the exchange (Eggertsson, 1990).

3.2.7 Water Allocations

In evaluating the effectiveness of water institutions in allocating water, security for users and flexibility over time must be considered (Livingston, 1995). Flexibility is critical because physical and economic conditions are subject to change over time and water allocations have to respond to such changes without causing high levels of insecurity or externalities (Easter and Tsur, 1995).

Allocations that do not satisfy Pareto optimal criteria are sub-optimal. Sub-optimal allocations always call for reallocations so that some people become better off and no one is harmed by the rearrangement. Normally in such arrangements the gainer would gain more than the loser loses. Therefore, the gainers could use a portion of their gains to compensate the losers sufficiently to ensure the losers were at least as well off as they were prior to the reallocation. That implies that net benefit to society becomes maximised as a result of the reallocation (Tietenberg, 1996). Theoretically therefore, allocations that fail to maximise net benefits forgo the opportunity to make some people better off without harming others.

According to Easter and Tsur (1995), the need for reallocation is reflected in the differences in shadow values among uses. But reallocations can pose problems for the design of institutional arrangements because greater flexibility can mean reduced security. For example, a non-transferable water right is very high in security but low in flexibility, while a tradable water right can be high in both security and flexibility as well as equalise shadow values among users.

3.2.8 Water pricing

This research focuses primarily on valuing water as a scarce resource. Emphasis is on the agricultural sector and specifically water stored in a reservoir for delivery to farm gates. The holistic approach to water pricing, involving among other factors, tariffs for water delivery, maintenance and other services in general, are beyond the scope of this work. From the theoretical viewpoint, water pricing is the basic instrument that helps to distribute limited water resources to users and to determine allocation of these resources by providing appropriate signals and incentives (Montginoul and Strosser, 1997)

Restrictions on water transfers and an absence of water markets are not the only sources of inefficiency in water allocation systems. Prices charged by water distribution utilities sometimes promote inefficiency (Tietenberg, 1996). Efficient pricing requires the use of marginal and not average cost. To adequately balance conservation with use, the customer should be paying the marginal cost of supplying the last unit of water (Tietenberg, 1996).

Where market-determined prices are allowed to dominate the allocation of a resource, market (price) equilibrium results in a balance between supply and demand that maximises consumer welfare. It implies that net benefits to society are maximised when the marginal increase in benefit equals the marginal cost. As explained by Figure 3.2, any divergence from this condition causes "a deadweight loss" as it is referred to in literature (Perry, Rock and Seckler 1997).

If prices are held at P_1 above the equilibrium price P_0, water demand is X_1 and non-optimal consumer welfare results. Furthermore, at P_2 below the equilibrium price, demand shifts to X_2 and the increase in cost incurred exceeds the increase in benefits to society at financial prices.

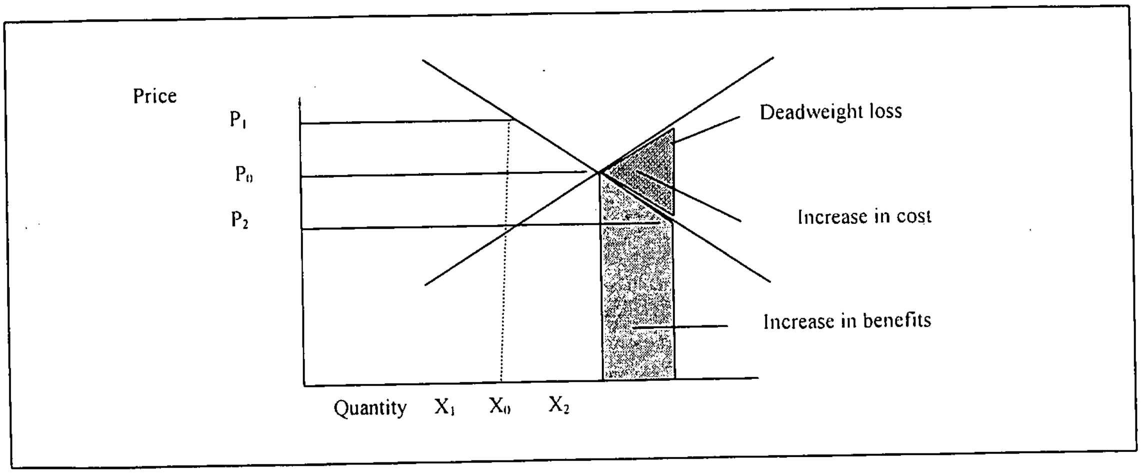


Figure 3.2: Equilibrium supply and demand showing "deadweight losses"
Source: Perry, Rock and Seckler, 1997

This implies that net benefits to society are only maximised when the marginal increase in benefit equals the marginal cost denoted by P_0 (Perry, Rock and Seckler, 1997). This price is, however, only theoretical, as explained by the Cobweb Model (Tietenberg, 1996) and unachievable in practice because of distortions in the market. As a result, no simple set of prices, especially in the case of water, is likely to provide the basis for the introduction of economic incentives to ensure optimum water allocation and use (Perry, Rock and Seckler, 1997). Due to this limitation, opportunity cost pricing is used to estimate this theoretical market price. Opportunity cost as a mechanism for pricing measures the benefit forgone when a scarce resource is used for one purpose instead of its next best alternative use (Gittinger, 1982). Louw and Van Schalkwyk (1997), on the assumption of a functional water market, developed a methodology for measuring the true value (scarcity value) of water in agriculture, based on opportunity cost. However, Briscoe (1997) stated that it is inappropriate to build opportunity costs in water tariffs, for three reasons:

- because information requirements are very demanding (i.e. opportunity costs vary dramatically according to place and season and even sophisticated research studies have to date not been able to estimate them in a way that is universally acceptable;
- because levying such charges would be perceived as expropriation by those who currently use the water; and
- because it would defy common sense. In Chile, Australia and California, for example, farmers would be asked to pay more than 10 times the value of their water if the cost of services they receive is built into the opportunity cost of water. Thus, a distinction has to be drawn between the value of water and the value of services, especially as water becomes scarce.

Under the circumstances one alternative would be to use shadow pricing. In this case a unit price other than the market price is used, so that the values of incremental outputs and costs are recalculated. Shadow prices are used instead of market prices, particularly when market prices of inputs do not reflect their opportunity cost (Merrette, 1997).

When water is considered as a production factor it should be allocated to the different uses by the market mechanism. On the contrary, if it represents a value of social use, then such value is essentially symbolic and non-monetary. Consequently water pricing could be a complex issue, with very strong political and cultural implications (Caldas, Sousa and Pereira, 1997). In spite of these complexities, a water-pricing system that allows fair allocation to the different sectors and leads to improvements in the efficiency of water use must be sought, particularly by countries that are faced with potential water scarcity in the near future. For water pricing to achieve allocation efficiency, demand for water must be sensitive to water prices. Furthermore, water users must easily understand the pricing mechanism and the mechanism must be stable enough over time to be in accordance with time horizons considered by farmers and other water users to take their decisions (Montginoul and Strosser, 1997).

3.2.9 Equity/Economic Efficiency

The recent successes of the California Water Bank (Howitt and Vaux, 1995; Easter and Archibald, 2001) demonstrate that economic incentives can be combined successfully with government regulations. To safeguard equity and future water uses, water management should not be carried solely through a market process or through a purely bureaucratic process. The ideal system would combine economic incentives, conflict resolution process and government action in a democratic system (Dinar and Loehman, 1995). To reduce conflict over transfers and promote equity, water banks as a modification of a water market process is recommended, as this would facilitate compensation to third parties through pricing mechanisms (Howe and Goodman, 1995). Water banks are institutions that stand ready to buy and sell water under some set of rules regarding which entities can participate and how prices are set. The banks can mark up water prices to cover transaction costs and could use the mark-up to provide compensation to the area of origin. The common problem with water banks however, is that the buying and selling prices are set arbitrarily and do not reflect market conditions (Howe and Goodman, 1995). Successes registered by the California water bank, where prices were set according to buyers' and sellers' marginal valuation of water, ensures efficient transactions between all participants. This sets a precedent worth emulating by those contemplating using water banks to mitigate certain conditions. Howe and Goodman (1995) recommend that water banks are given much more serious consideration as a component of state water management. Furthermore prices offered and accepted by the banks should be set to guarantee sufficient compensation, so that the water transfer would constitute a Pareto improvement. It is also essential that competent public bodies are responsible for determining any protection and/or compensation offered by the banks.

If water resources are divided in an equitable manner at the outset by say legislation, the question of fair distribution would be settled. Thereafter, owners now possessing their fair shares of the resource can compete and trade in the market. As a result of market competition, efficiency is achieved in the manner suggested by the first welfare theorem, and the final economic outcomes are deemed not only efficient but also equitable (Chan, 1995).

3.3 WATER INSTITUTIONAL FRAMEWORK

Figure 3.3 has been developed from institutional economic theory, and offers a generic water institutional framework aimed at guiding institutional arrangements towards achieving economic as well as socio-economic objectives, while and at the same time guaranteeing water security.

Structuring institutions to promote sound and sustainable economic development poses a critical challenge, especially for developing countries like South Africa. Successful water institutions will require a delicate interplay between the public and private sectors (Easter and Tsur, 1995). This framework will therefore embrace the approach that will integrate both public and private sector involvement and provide market forces with the chance to facilitate the reallocation of water with the essential goals of allocation efficiency, economic efficiency, promotion of sound investment and economic activities, achieving socio-economic sustainability and, above all, water security. The linkages between these goals and those in the South African Water Act will be discussed later (see Paragraph 3.6).

However, if water allocations (as well as reallocations) are sub-optimal, economic efficiency of the resource use will be seriously jeopardised. Investments and economic activity will be slow and could possibly grind to a halt, as most water use sectors will not be optimally activated. The resultant effect will be slow economic development with its social connotations. Also, inappropriate allocations will not promote sustainable use and water security will be a mere dream that will hardly be realised. The goals that are listed in the framework are thus formulated to generally meet the objectives of any water management organisation that strives for perpetual water security.

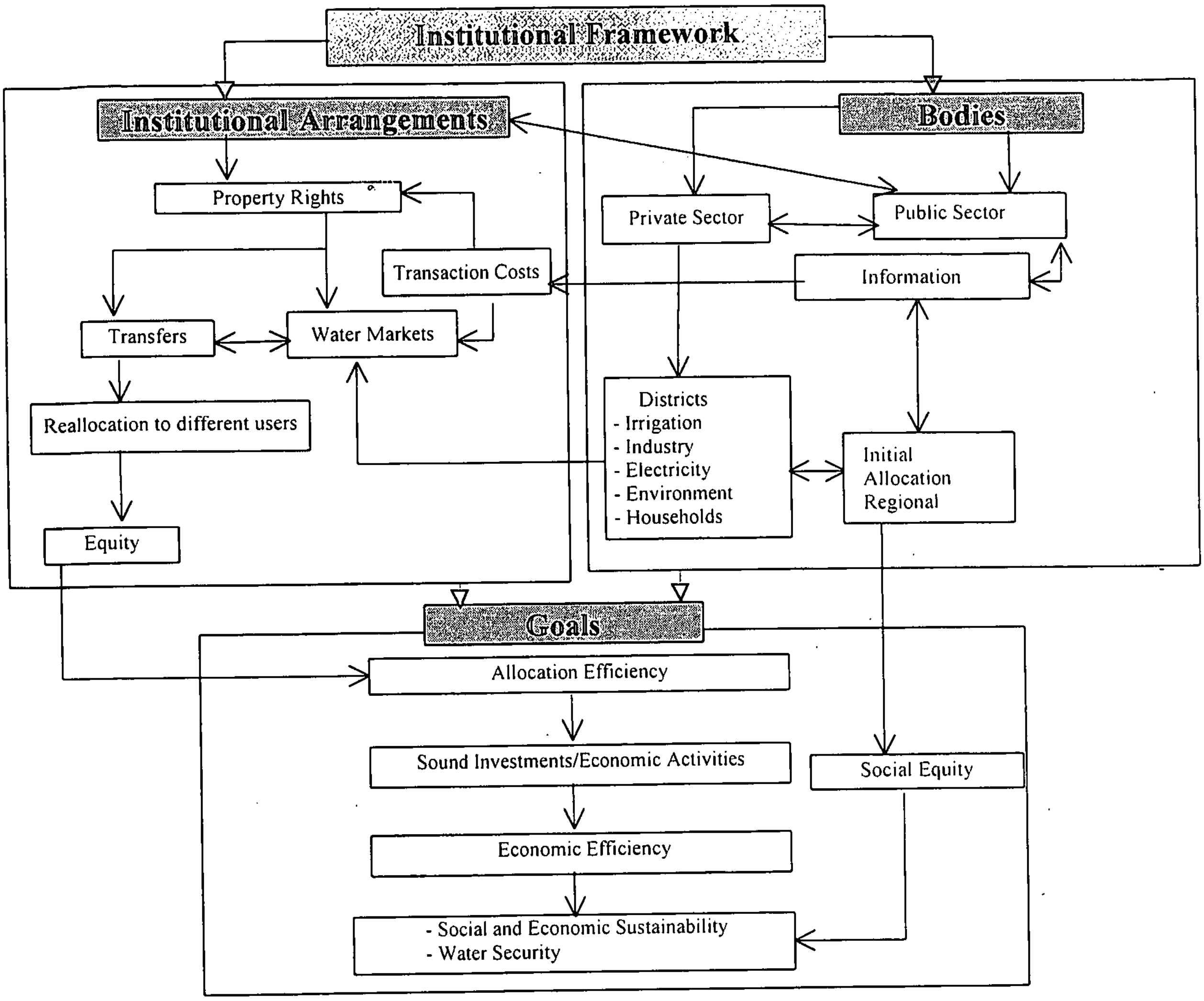


Figure 3.3: **Proposed ideal institutional framework for achievement of water security**

In this framework the role of each sector is demarcated clearly. The public sector's (Central Water Agency) role will be to:

- ensure that the appropriate institutional arrangement is in place for a successful management of water resources, i.e. to establish water rights, set rules for trading in water and water rights and monitor as well as enforce these rules and mediate in conflicts, make changes in the structure of water rights and rules for trading as time goes by and conditions change;

- establish a national information system that covers virtually all aspects of water resources (quality, quantity, demand, supply, floods, droughts etc). This information system will assist the Central Water Agency in the full assessment of water resources and consequently promote a fair allocation of water endowments to the districts through the regions. Relevant, adequate and timely information received and disseminated by the public sector will impact positively on transaction costs and hence facilitate exchange of property rights.

Thus the public sector will be restricted to making laws, collecting all the relevant and accurate information on time and initially allocate water to the districts through the regions.

The private sector (Figure 3.3) will be involved in water management mainly at the district level. Water management at this level has to be largely private, to facilitate the development of water markets that would allow water to flow to the highest value uses. Other roles of the private sector will include operation and maintenance, and inducing technological innovations that will progressively promote overall (production, consumption or investment) efficiency. The private sector also has to co-operate with government at water management levels where joint ventures will be necessary for the attainment of specific objectives like social equity.

To achieve allocation efficiency, sub-regional or district level reallocations will be left to the districts. With water rights guaranteed institutionally, the way becomes paved for transfers and water market operations. The districts will rely heavily on the market forces and the transfer mechanisms, which are established to reallocate water to their most valued uses. The opportunity cost of water between different water use sectors, between districts or between users in the same sector, will guide the markets in terms of pricing. The difficulties associated with opportunity cost pricing can be resolved by introducing appropriate mechanisms that will allow shadow prices to be used as good estimates of opportunity costs. Public sector involvement in the market would be limited, for the protection of sectors such as the environment and domestic consumption referred to as “reserve” so as to reduce distortions and market failure. Equity driven re-allocations should lead to optimal allocations. However allocations to address social equity needs have to be safeguarded by the public sector through regional allocation mechanisms.

Allocation efficiency is the gateway to the achievement of virtually all the other objectives. With an efficient dynamic and functional allocation mechanism, water users, especially irrigation farmers, can be sure that all sub-optimal allocations will be reallocated in the market until the possible best optimal allocation is attained. Consequently, this may lead to sustainable economic activity and efficient investment decision making, which will culminate in overall economic efficiency. With these objectives reached, socio-economic sustainability and water security goals cannot be compromised.

3.4 INTERNATIONAL TRENDS AND PATTERNS IN WATER POLICY AND INSTITUTIONAL ARRANGEMENTS

The evolution of water-related institutional arrangements in selected countries internationally is summarised to disclose global trends. The countries under discussion include Chile, Mexico, Australia, Israel, United States, Zimbabwe, China and Sri Lanka. Among the countries listed above, six were included in the eleven countries earlier studied by Saleth and Dinar (1999). The Western United States is added mainly because of the level of water scarcity in that region, and Zimbabwe's inclusion stems from the recent changes in its water laws and the fact that decentralisation is receiving considerable attention. Thus, selecting the sample from different continents, historical backgrounds, political systems, demographic trends and water scarcity levels, convincingly shows that the sample is a good representation of the reality of global water institutions in their relevant dimensions. A more elaborate classification of the countries follows in Table 3.1.

3.4.1 Mexico

Mexico has a strong central government and water resources management issues are theoretically held by the *Comision Nacional de Agua* (CNA) for the Mexican people. The economic liberalisation of the country in early 1990's, during which the country shifted from a centralised highly regulated system to a market-based system, resulted in the legalisation of water markets under a new Mexican water law of 1992 (Rosegrant and Schleyer, 1994). The water law established water use rights for individual users for five to fifty years on a volumetric basis, separate from land ownership or use (Easter and Feder, 1996). Water concessions, in which the use and discharge have not changed, are generally renewed by the CNA, however the renewal of concessions involving a change in the use or discharge is considered subject to the overall river basin supply and demand. The new water law allows private and transferable use rights but limits such transfers only within the sector, as water transfers involving a change of use require prior approval (Saleth and Dinar, 1999).

Table 3.1: Classification of selected countries for water institutional trend study, 2001.

Water resource endowment	Country	Type of government	Stage in institutional reform	Level of Water Scarcity	Population
Large resource endowment	Mexico	Central	Intermediate	Verge of scarcity	98 million
	Australia	Federation (autonomous states)	Advanced	Surplus to marginally vulnerable	18 million
	USA	Federal	Advanced	Marginally vulnerable	281 million
	China	Central political	Intermediate	Varies (Flood/ drought) prone	1.2 billion
Medium resource endowment	Chile	Unitary	Advanced	Surplus	14 million
	Zimbabwe	Democratic	Intermediate	Stress	12 million
	Sri Lanka	Federal	Progressive (but low)	Stress	17.6 million
Small resource endowment	Israel	Unitary	Advanced	Acute Shortage	5.7 million

Individual users within irrigation districts (IDs) are organised into compulsory WUAs. These bodies determine the reallocation of water concessions to individual farmers (Easter and Hearne, 1994). WUAs are charged with the development of procedures to allocate surplus and deficit water within their control and all such deficits and surpluses are allocated proportionally across users (Rosegrant, Schleyer and Yadav, 1995).

The Mexican Water Law allows markets to operate freely within irrigation districts or WUAs, whiles government plays a well-defined role of water planning and allocation. The responsibility of water management is decentralised to WUAs, who oversee the effectiveness of the water market. In most circumstances WUAs enjoy the autonomy to make infrastructure changes, and can effect changes in allocation rules to ensure buyers of water rights receive the additional supply (Easter and Hearne, 1994).

3.4.2 Australia

In Australia, states have the constitutional responsibility for water resource management, but the central government also has a considerable influence on the water sector. The 1994 Water Reform Agreement of the Council of Australia Governments (COAG), that aims to unify and strengthen both state and national water institutions, justifies the national level perspective in water institutions in Australia (Saleth and Dinar, 1999). The water institutions of Australia originally had features suitable more to a water abundance situation than to the dry reality prevalent in larger parts of Australia. Although these institutions underwent a process of natural evolution in line with changing water resource realities, a series of reforms effected since the late eighties led to some marked changes (Musgrave, 1997).

The riparian system of water use was replaced by a water license system, which allowed quantitative entitlements, and metered supply and volumetric pricing of water (McGlynn, 1997). Licenses are issued and regulated by government departments. Although the licenses linked to the land the reform of the 1980's have enabled them to be transferable, creating the basic framework not only for cost recovery but also for the emergence of water markets. Water is metered widely and pricing is based on volumetric consumption. Inter-state and inter-regional issues are addressed through river basin organisations operating within an inter/intra-regional allocation framework conducive for market-based solutions. The New South Wales (NSW) water sector, in particular, and Australia water sector in general, have one of the best institutional arrangements that promote a desirable mix of administrative regulation and economic instruments (Saleth and Dinar, 1999).

Although water institutions in Australia are far more advanced than those in other countries, they are not immune to challenges. The demand pressure on available water resources has become intense, especially after the legally mandated water entitlements for the environment. Thus the water sector is neither free from serious problems nor are existing water institutions adequate to meet all future water allocation challenges. Some of the major outstanding problems facing the Australian water sector include the fine-tuning of the institutional basis for water sharing and market based allocations, and extending the substitution of economic instruments for administrative regulations (Saleth and Dinar, 1999). These problems are however, seen as challenges facing a matured water economy that tries to operate increasingly on an economic rather than on administrative or political realm.

The early realisation that appropriate property rights arrangements designed for market- based solutions are essential (Watson, 1990), paved way for an innovative property rights system like capacity sharing to be developed (Dudley and Musgrave, 1988). Current institutional arrangements associated with new transferability policies, ensuring socially optimal resource allocation and economic efficiency are dominant. In the past resource allocations were generally administratively based with minimal public information flows on prices, quantities and qualities. Alternative market based institutional arrangements (e.g. auctions) to facilitate the public flow of information required for efficient resource allocation decisions were considered. However, it was realised that appropriate property rights arrangements designed for market-based solutions are an essential pre-requisite. This called for an innovative market based property right system capacity sharing to be developed (see Dudley and Musgrave, 1988).

The appropriateness of capacity sharing for irrigation and other purposes in that environment, led to the incorporation of provision for its use in recent legislation passed by the Victorian government (Dudley, 1992). Strong evidence exists that CS provides a superior framework for water allocation compared to most alternatives. In Victoria, Australia, the concept has been enacted on the bulk capacity sharing level and had been a vital instrument in resolving conflicts between her and New South Wales over their sharing of the water resources (Scott, 1994). Furthermore, in the Namoi River Valley, farmers have favourably accepted the concept of capacity sharing and eagerly await its implementation, as they believe it will resolve their water management problems permanently. The ongoing institutional changes in Australia continue to strengthen the role of economic instruments and market-based water allocations while at the same time improving physical health and sustainability of the water sector.

3.4.3 United States of America

Water rights transfers occur widely in the Western US, where increasing water scarcity is prevalent. The evolution of the water economy has encouraged the development of a physical and institutional infrastructure for water marketing (Colby, 1990). Mechanisms for reallocating water among water users on a voluntary basis are popular. Transactions normally involve transfers from lower to higher valued uses. Transfers from the agricultural sector to higher valued non-agricultural uses generate more revenue than within the agricultural sector. But transfers within the agricultural sector are common (Shupe, Weatherford and Checchio, 1989). The transfers are short-term, seasonal arrangements within an irrigation district. Generally, these transfers are not subject to state review. In most states, changes in the point of diversion, place of use, and/or purpose of use under an existing appropriative water right may be made subject to the requirement that there is no impairment of other existing water rights (MacDonnell, 1990).

For the allocation of water the Western US relies on the prior appropriation doctrine, which supports ownership of water rights. This form of institutional arrangement makes provision for explicitly defined water rights that are enforceable and allows trading (Anderson and Leal, 1989). Water rights are defined by State law in terms of quantity that may be diverted, as well as priority. The priority of rights permits a user to buy varying quantities of water. However, organisation of the market becomes difficult due to the heterogeneous nature of rights resulting from varying priority of rights (Rosegrant, Schleyer and Yadav, 1995).

In summary, the water law that evolved in the Western United States reflects the scarcity of water in the region. According to Anderson (1983), efforts were directed at defining and enforcing property rights, which culminated in a system that:

- granted an exclusive water right to the first appropriator and then later appropriators on condition that prior rights were met;
- permitted diversions of water for use on non-riparian lands;
- encouraged forfeiture of rights if water was not used; and
- allowed for the transfer and exchange of rights in water between individuals.

3.4.4 China

China has a centralised political system with considerable decentralisation of power at all layers of government. In the water sector, legislative and regulatory powers as well as planning and development responsibilities resides with the national government but actual management and maintenance functions reside with lower level government, depending on factors such as size and location of projects (Saleth and Dinar, 1999). The Ministry of Water Resources (MOWR) forms the core of the national level water administration in the country. The next level of administrative organs are seven Water Conservancy Commissions (WCCs), which are regional arms of the MOWR essentially designed to manage inter-provincial river basin and lake zones. Other administrative organs at lower levels include bureaus of water conservancy and irrigation area congresses (similar in operation to WUAs). Quite a substantial functional specialisation and management decentralisation exist across all government layers as 77 per cent of all water projects in the country are managed at regional level and the rest at provincial level or by the MOWR and its WCCs (Ke Lidan, 1997).

In 1988, after consultations over about a decade, a water law was passed with the aim of strengthening the regulatory powers of the existing administrative system and formalising mechanisms for management co-ordination and conflict resolution. It marked a fundamental change both in water policy and water administration in China. The law considers water as the property of the people and distinguishes clearly between the management and allocation rights of the state and the user rights of the people. It also calls for permit-based water allocation, full cost-based water charges, stipulates basin as the basic unit of water management and mandates the formulation of a national water plan that includes regional and sectoral components (Saleth and Dinar, 1999).

The State Water Industry Policy declaration in 1997, allows, for the first time, the entry of private and non-governmental organisations into the water sector and also stipulates the operation of all public water projects on commercial lines (PRC, 1997). It is worth noting_that the issue of water permits is already in progress. However, the creation of a full institutional structure necessary to support the permit-based water allocation system, is expected to be in place by 2010. When this happens it is alleged that China will be the first country to have a national level water institution centred on a legalised system of water allocation (Saleth and Dinar, 1999).

3.4.5 Chile

Chile presents one of the earliest and the most developed institutional arrangements favourable for market-based water allocation, decentralised management and private sector participation. Prior to the early 1980s, Chilean water law considered water resources as a common property, but for all practical purposes, water was treated as private property attached to land (Saleth and Dinar, 1999)

This situation changed dramatically as a result of the 1981 Water Code and 1988 constitution. Water use right is treated both legally and practically as a private property independent of land that can be traded, used as collateral, also as an asset for tax purposes (Gazmuri and Rosegrant, 1994). Policy reforms were directed at facilitating efficiency and flexibility in resource allocation in agriculture.

These policies also include the redistribution of water and land to the private sector, the definition of well-defined water and land property rights, and market allocation of the two resources (Saleth and Dinar, 1999). The initial allocations of water rights appeared to have been met by basing allocations on historical water rights and some redistribution of concentrated rights holdings (Rosegrant, Schleyer and Yadav, 1995).

The National water administration has clearly defined responsibilities between water-related state organisations, water supply and sewage services agencies, private construction companies and Water User Associations (WUAs).

The state retains the right to grant quantified water rights to all users, while the active water market is left to facilitate reallocations of such entitlements both within and across water use sectors (Hearne and Easter, 1995). WUAs and courts play the conflict resolution role. The policy of market allocation and privatisation in Chile is accompanied by state protection to poor farmers and urban users through a policy of demand rather than supply side subsidy. This implies that the poor pay the same price but receive a lump sum subsidy to cover their excess water bills. Despite the advanced nature of the Chilean institutional arrangement, Saleth and Dinar (1999) documented some of its key challenges as follows:

- Growing inter-sectoral conflicts between irrigation and power generation as well as between irrigation and urban users.
- Countering speculation in water rights that encourage non-use, especially by electric power companies.
- Ensuring minimum in-stream flow in ecologically sensitive rivers or streams especially by assigning the right on return flows to the environment.

Currently notable legal and policy initiatives address some of these issues. Recently, the decision by the Supreme Court upheld farmers' claims over that of electric power companies. This step set a precedent and a sound legal basis for conflict resolution between uses related to consumption and those unrelated to consumption. To avoid speculation and discourage large-scale water rights transfers from agriculture to power and urban sectors, a legislative proposal in 1992 suggested two key aspects:

- Forfeiture if not used over five years; and
- limiting rights to specific use.

Although these proposed changes are interpreted as risking both the security and transferability of water rights (Gazmuri and Rosegrant, 1994) they are essential factors in maintaining a balance in inter-sectoral allocations to prevent monopoly tendencies and encourage better water utilisation (Saleth and Dinar, 1999).

3.4.6 Zimbabwe

The current institutional arrangement prevailing in Zimbabwe is a replica of that existing in South Africa. With reference to the Zimbabwe National Water Authority Act, 1998, all water is vested in the President, thus removing the concept of private ownership of water. Currently the concept of water rights as real rights issued in perpetuity to the land in respect of which they are granted, is not applicable and has been replaced by a permit system according to which permits will be issued for the use of water. The preferential rights to water held by riparian owners have been abolished. Catchment Councils (CCs) set up to manage water in their respective catchments are now granted power to issue permits required for certain uses of water, thus decentralising and removing this function from the Administrative Courts.

Permits are granted for twenty years or such shorter or longer time as the CCs might decide. Provisions are made for CCs to be representative of all water users in the area concerned with the intention that people in the communal and resettlement areas are involved in water management. The Act's provision for the establishment of combined water schemes is also extended beyond irrigation to other commercial purposes. The institutional provision for combined water schemes is a boost for Capacity Sharing (CS).

Within the framework of the past institutional changes and the current institutional arrangement, a thriving water management system typical of capacity sharing was initiated as early as 1984 by an eleven-member Combined Irrigation Scheme (CIS) and is and it has since developed to national proportions. The attention and interest of the water Ministry was drawn to fact that members of the CIS preferred to manage their own share of stored water and manage their own risk independently. Although the concept was revolutionary and untried, approval was given for this type of management system to be formulated (Doertenbach, 1988).

The water in the reservoir was treated like money in the bank. Each of the participants was given a separate "account", with a facility for both "deposits" and "withdrawals". The new water to which the parent water right was entitled each month was quantified, separated into the appropriate percentages or fractions and "deposited" into each individual account. There is absolute equity of access to the new water available each month and participants manage their own risk of supply independently.

CS has been successfully implemented in a total of eight private, medium sized and multi-participant reservoirs. It is currently considered to be time tested and a successful water allocation method in Zimbabwe (Doertenbach, 1998).

The new management system received broad approval from both the CIS members and non-member rights holders. It was simple to calculate, easy to understand, mathematically verifiable and transparent. Natural river flow was quantified more accurately than ever before and was readily available to those with rights to river flow. The management system also satisfied the original requirements of the CIS participants, all of whom were free to manage their own stored water and risk of failure as their individual financial circumstances required, just as if they were owners of individual private reservoirs.

The success of this new management system "capacity sharing" meant that private and individual risk management of multi-participant reservoirs was a legitimate alternative to traditional government-style risk management, which required central determination and management of risk. As soon as individual management became possible, new multi-partner schemes became very popular (Doertenbach, 1998).

3.4.7 Sri Lanka

Following constitutional amendments that transformed government from a unitary state to a federal system, water sector responsibilities were divided between the central government and provincial councils in 1990. All intra-provincial irrigation planning, implementation and management reside with the provincial governments, while the responsibilities for inter-provincial irrigation schemes and overall water resource planning, water storage, drainage and flood protection reside with the union government.

As many as 40 government agencies wield a varying degree of influence over the water sector, but only seven are significant as they form the core of water administration at the national level (Saleth and Dinar, 1999). At the moment, over 50 different Acts influence the water sector, but the country has neither an enacted water law nor a declared water policy required to provide the legal framework for an integrated approach to water resources management. A draft Water Resources Bill under discussion since the early 1980's, though not adopted, contains all the ingredients for a modern water law. This bill advocates water permit systems, full cost pricing, an inter-ministerial Water Resource Council as a co-ordination mechanism, and water courts for conflict resolution (World Bank, 1992).

Recently technical and financial support from donor agencies prompted the government to plan a major change in the legal and administrative spheres of the water sector. Thus an action plan for comprehensive water resource management was instituted. This plan calls for the development of water policy, water law, autonomous water administration, basin planning and a water information base. It was further suggested that the Water Research Council and its executive organ, Water Resources Secretariat, be created. These two institutions have since been established as transitory arrangements to advise, develop and oversee a permanent institutional arrangement. The outline for a new institutional structure developed by the two institutions is expected to be in place by this time (Berkoff, 1997). As a result of the creation of institutional structures at macro level and the consolidation of management decentralisation and privatisation efforts initiated at micro level, the Sri Lankan water sector is quite well placed to tackle its water management problems of the future.

3.4.8 Israel

The 1959 water law that makes water a public property remains the foundation of the present water policy and water administration. Although water policy and administration are centralised with political voice, the water sector in Israel is subject to strong economic influences. Volumetric allocations and strict economic pricing are prevalent. Inter sectoral water allocation is done administratively on political grounds to favour domestic and industrial sectors, but water prices in these sectors are higher and cover full cost (Saleth and Dinar, 1999). Irrigation water is subsidised, but this has declined by a third since progressive block rate pricing was introduced to penalise large and fresh water consumers (Yaron, 1997). Recently a legislative proposal was placed before parliament, aimed at enhancing private sector role in areas such as urban water distribution, operation and maintenance and sewage treatment. There is increasing support for the promotion of market-based water allocations as well as the adoption of a pricing scheme that also includes a shadow price for water as a resource (Kislev, 1993).

3.4.9 General international trends/patterns

It is evident from the discussion of the countries listed above that nations vary in terms of size, political system and developmental stages, yet they share certain common traits in terms of their main water sector problems and hence the institutional arrangements for resolving these problems.

Saleth and Dinar (1999) revealed that the water sector problems common to most of the sampled countries include:

- increasing relative water scarcity;
- water quality deterioration;
- inter-sectoral and inter-regional water allocation conflicts;
- poor cost recovery and operational performance;
- excessive government involvement and bureaucratic control; and
- out-of-date institutional arrangements.

Institutional changes are thus, in most cases, structured to address these issues, with the origin and their inter-connections determining countries' specific strategies for water sector reform. These linkages have obvious and far-reaching effects on the financial, economic and physical dimensions of water sectors. What is not that obvious is the fact that these connections have their origin in the institutional dimensions in so far as they result from legal issues like ownership, policy issues like water pricing and administrative issues like investment and cost recovery arrangement.

The central problem is identified to be too much government involvement in water development and the resultant bureaucratic control, which often creates passive users *and rigid administrative systems that are incapable of responding quickly to market forces* (Saleth and Dinar, 1999).

With binding physical, financial and ecological limits to supply-side solutions, countries are generally trying their utmost within their political economy constraints to set right the institutional foundation for their water sector. These efforts are reflected in legal, policy and administrative reform. Current water institutional changes observed at international level reflect, according to Saleth and Dinar (1999), a common and remarkable pattern of focus and direction regarding:

- shift from development to allocation;
- emphasis on decentralisation and privatisation;
- integrated approach to water management; and
- premium for economic viability and physical sustainability.

All countries, even those with tradable private water use rights (e.g. Australia and Chile) have asserted the overall regulatory and allocation rights of the state. But nowhere, not even in China, is the state's absolute ownership of water established to exclude private use rights. In actual fact, all the countries studied have explicitly recognised private water use rights and most of the countries (except China and Sri Lanka) are in the process of establishing transferable water rights, including pollution permits. Furthermore, realisation of the need for decentralisation in all the countries increasingly emphasises the importance of the formation of the river basin organisations. These organisations have different names in different countries (e.g. Watershed Committees in Brazil, Water Conservancy Commission in China, Basin Councils in Mexico, and Catchment Management Agencies in South Africa). These organisations may vary in terms of their administrative arrangements and fractional autonomy but operate on common conceptual bases and organisational features. In all cases they function as planning and allocation mechanisms and pursue an integrated approach to water resource management.

In summary it can be stated convincingly that concerns in the water sector which once centred around water development and quantity, now revolve around water allocation and quality. The old paradigm which focused on centralised decision making, administrative regulation and bureaucratic allocation is rapidly giving way to a focus *on decentralised allocation economic instruments and stakeholder participation* (Saleth and Dinar, 1999).

3.5 SOUTH AFRICAN WATER INSTITUTIONAL FRAMEWORK

3.5.1 Institutional framework prior to 1956

Historically, water law in South Africa evolved according to the changes set in motion by the social, economic and political developments as they took place on the subcontinent. During the era of Dutch Settlers all land was held in freehold, the state had ownership of all water and absolute control over its use, under Roman-Dutch law principles.

In 1814, when the Cape became a British Colony, land was under freehold tenure, with associated natural rights attached to the land belonging to the landowners. Consequently, the riparian principle of English-American Law was firmly established in water law (Rowlston, Barta and Mokonyane, 2000). Water courts were set up to arbitrate on individual water rights and to determine water allocations. The state played only a limited role in water resource development, which was dominated by private agrarian developers who concentrated primarily on irrigation advancements. Village and town authorities were fully responsible for the water supply and sanitation needs of local inhabitants.

The creation of the Union of South Africa in 1910 paved way for the first nationally applicable water legislation namely the Irrigation Conservation of Water Act of 1912 (Rowlston, Barta and Mokonyane, 2000). The riparian principle remained the central feature of water law, but state involvement in water resources management was limited to irrigation related works. Urban and industrial growth required frequent deviations from the riparian principle, and the water courts were consequently empowered to authorise the use of "public" water on non-riparian land (Backeberg, 1994)

3.5.2 Institutional Framework 1956-1994

Post World War II industrial development in South Africa required water legislation to be adjusted and this gave birth to the 1956 Water Act. The act consolidated control, conservation and use of water for domestic, agriculture, urban and industrial purposes. This Act perpetuated the riparian principle of "normal" flow and "private" water, which granted exclusive use but not ownership (Government Gazette No 5718, 1956).

Numerous Government Water Control areas were established over which water courts had no jurisdiction. The state played a major role in planning and implementing water resource development. In actual fact, all aspects of water management were centrally controlled with considerable power vested in the minister. Also during this era, legislation and management policies regarding water resources management and service provisions have historically favoured only specific water use sectors and population groups. Economic and development goals took precedence over environmental and social ones. In the early 1990's, when the new South Africa dawned, socio-economic and legal systems underwent fundamental restructuring.

After the first national democratic elections in 1994, the government introduced a new socio-economic doctrine focusing on equity and sustainability as the major objectives of national development policy. This led to the enactment of two new water laws in 1997 and 1998 namely. the Water Services Act (WSA) No. 108 of 1997; and the National Water Act (NWA). No. 36 of 1998. Jointly the two new laws provide an integrated legislative framework within which South Africa's water resources can be managed.

3.5.3 The present water law

3.5.3.1 Development

A host of factors were taken into consideration in promulgating the new Water Act. The need for reviewing the South African Water Law and for fundamentally changing the approach to water management was dictated by the new Constitution, which was structured to create a more just and equitable society (Rowlston, Barta and Mokonyane, 2000). The first of the series of principles on which the Water Law was developed confirmed this by stating (Department of Water Affairs and Forestry, 1997):

"The Water Law shall be subject to and consistent with the Constitution in all matters including the determination of the public interest and the rights and obligations of all parties, public and private, with regard to water. While taking cognisance of existing uses, the Water Law will actively promote the values enshrined in the Bill of Rights."

The Bill of Rights stressed, among other rights, the right to, equality; the right to dignity and life, and the right to a healthy and sustainable environment. It has thus become the duty of the National Government, through legislation, to ensure equitable access to sufficient and clean water to support life and guarantee human dignity, as well as prevent pollution and maintain the ecological integrity of the national water resources. In addition, government is to ensure that water conservation and sustainable use are promoted. Another main factor is the continuous growth in pressure on the water resources as a result of ever increasing water users.

It is thus important to emphasise that the reform of South Africa water law has been not only driven by the demands of equity and social transformation. Even without political change, the basic reality would still have to be addressed, as the same amount of water, if not less, has to be shared between larger users and the growing needs of our developing society (Muller, 2000).

3.5.3.2 Provisions

Essentially, the provisions made for water allocation; user rights; and all matters relating to the general management of water resources are extracted from the NWA (Government Gazette, 1998). For the purpose of this research only the relevant sections focusing on pertinent issues that have bearing mainly on economic sustainability, efficient allocation and sustainable use of water resources were extracted (see Appendix C).

3.6 EVALUATION OF THE SOUTH AFRICAN WATER ACT

The proposed ideal institutional framework that is presented in Figure 3.3 can be useful in unveiling the strengths and weaknesses of institutional arrangements globally. The integrated approach to water resource management through the appropriate institutional arrangements involving institutions both private and public, setting non-conflicting objectives and goals as in this framework augurs well for any water sector.

Current international trends discussed earlier, gave considerable recognition to decentralised allocation mechanisms and the phasing in of economic instruments as reflected by this ideal framework. With the idea of water provision as a public good and pure welfare activity becoming outdated, policy concerns are geared more towards financial viability, efficient and equitable use, integrated demand and supply management as well as cost recovery. All these concerns are well provided for in the developed framework above. It is evident that international approaches to address water sector crises via institutional arrangements, are country specific but generally correspond significantly to this framework.

The new National Water Act (NWA) of South Africa is drawing international attention for its position regarding its identification of and efforts towards address issues such as:

- guaranteeing access to sufficient water for basic needs;
- ensuring that the requirements of the environment are met;
- sustainability and renew ability of water resources;
- provisions for the transfer of water between catchments;
- honouring obligations to its neighbours; and
- fulfilling commitments as custodian of the nation's water resources.

As reported by the Department of Water Affairs and Forestry, (1997) the direction of water management in South Africa was shaped by landmark international events such as the United Nations Conference on the Human Environment (Stockholm 1992); the International Drinking Water Supply and Sanitation Decade lunch (Mar del Plata, 1977); the World Conference on Water and the Environment (Dublin, 1992); the

Earth Summit – Agenda 21 (Rio de Janeiro, 1992); the Global Water Partnership meeting (Stockholm, 1996) and the First World Water Forum of the World Water Council (Marrakech, 1997). South Africa's initiative to address water policy in such a structured and principled way has attracted great interest.

Saleth and Dinar (1999) in their World Bank report, complimented South Africa for the legal provisions made in its water law. These provisions include the creation of a market-based water sector and the imposition of water charges to cover not only the operation and maintenance as well as capital costs but also the cost of water management, conservation and research. Also, the importance attached to catchment management, the operation of water courts and the improvement in irrigation technology were favourably noted. However, the report identified a major challenge concerning achieving the equity goal of water redistribution to favour the previously neglected groups without creating uncertainty among investors. The report also casts considerable doubt on the implementation of the reform proposals in their original form without much political compromise.

Despite the remarkable provisions, there is still room for improvement in the institutional arrangements. An earlier evaluation of the NWA of South Africa identified some critical issues which need serious revision. The NWA is considered to have provided the framework for water markets in South Africa. Also for the first time in South African water legislation, statements regarding water trading are included as a policy option for water allocation. However, preference is still given to administrative price setting for water resources, and the effected legislation makes vague provisions for legal water transfers of water use licenses.

It is feared that the NWA will not facilitate market trades of water use licenses. Also the unclear legislation regarding water trading creates much uncertainty about legal water trades, and the extent of bureaucratic control and regulation of water trading in the NWA creates highly restrictive conditions for voluntary transfers between willing transactors. It was also identified that government has assumed exclusive responsibility for water allocation, putting public interest above any private concerns in the evaluation of efficiency (Armitage and Nieuwoudt, 1998).

Easter and Tsur (1995), support government involvement in water resource management. The extent of involvement is however limited to the provision of physical infrastructure, defining the rules for water management and maintaining institutions to monitor and enforce these rules. On the contrary, NWA clearly empowers the minister to regulate the use and flow, as well as exercise absolute control over all water. This provision is tantamount to a central administrative approach to water management, which is out of line with the ideal institutional arrangement and current international trends. Provisions are made subjecting all water management institutions to directives from government. The establishment of CMAs and WUAs, currently in progress, creates the hope for decentralisation and community involvement. However, these institutions may only enjoy limited leverage regarding regulation of water use and the fact that they will only act on assignment or delegation crystallises to central administration, hence their water reallocation role is likely to be influenced by ministerial or bureaucratic decisions.

The issue of granting permits is a good idea and is working quite well in successful water economies like Australia, Israel and Chile. In Australia, for example, the riparian system in a reform process was replaced by water license system, which over time allowed quantitative entitlements, metered supply and volumetric pricing. Although these licenses were originally attached to land, later reforms enabled them to be transferable, creating the basic framework not only for cost recovery but also for the emergence of water markets.

A mere replacement of the riparian system in South Africa with a five-year permit whose renewal is subject to ministerial approval, could be damaging to the macro economy in the long run. The reason for this is that a five-year license without a reasonable guarantee of renewal is equivalent to attenuation of rights to use water, thereby creating uncertainty, which in the end becomes harmful to long-term investment decision making.

The role of government in granting initial allocations based on the state of resource endowments and social equity needs conforms to international norms or practice. However, reallocations in an effort to achieve economic efficiency have to be left to the water market. But two factors of grave concern will have to be addressed first.

These include obtaining user rights and securing funds to participate in the market process. Backeberg (1997) mentioned that besides holding user rights, individuals must have access in order to be able to participate in the water marketing process.

With widespread poverty, stemming from the legacy of past policies especially in the rural areas of South Africa, where untold hardships are prevalent, constructive policy measures are necessary to arrest the situation. For the immediate short term, (Backeberg, 1997) suggests that grants or loans with favourable conditions must be provided to the underprivileged to enable them to acquire water user rights. Empowerment of this multitude of smallholder water users (irrigation farmers) may contribute to the success of a dynamic water market, since one of the prerequisites for an efficient and effective water market is numerous participants with an effective demand. Provisions in the NWA are found to be seriously lacking in this regard.

Administrative pricing, which compromises efficient water use, still remains popular with South African Water Management, despite the acknowledgement that other forms of pricing, for instance auctions or tradable entitlements, have great benefits. With public auction restricted to water-stressed areas and tradable entitlements subject to ministerial control in a bid to protect public interest, pricing via these approaches certainly becomes inferior to the government approved administrative approach. Economic charges levied administratively and based on the opportunity cost of water is to be considered from the date when the period of compulsory licenses in water management expires.

Thobani, (1997) emphasises that measuring opportunity costs under administrative price setting is impossible and states that it could possibly lead to the implementation of inappropriate price structures. This may be considered a major source of inefficiency and has to be addressed by an alternative pricing mechanism. A possible alternative, such as shadow pricing, will be appropriate for estimating the opportunity cost. Public officials may also lack the necessary information regarding individual water users, such as farmers and their operating environment, thus resulting in the implementation of inappropriate price structures (Anderson and Leal, 1989). An ideal institutional framework will have to make ample provision for gathering and disseminating information to address such issues.

The view of the National Government is that tradable water use entitlements will promote the shift from low to high value users of water and may obviate the need for administratively set prices in the water-stressed area experiencing an increasing water demand. According to Department of Water Affairs and Forestry (1999b), the advantage of making water use entitlements tradable is that it allows a more efficient user to buy the entitlement from an existing but less efficient holder of the entitlement. Yet the provision in the NWA subjects trading in entitlements to some form of control which developed from the fear of external cost being imposed on the rest of the economy. The creation of a market-based water sector is thus high on the agenda, what remains is a concerted effort by both the public and private sectors to identify these feared external factors that impede free market operations. This is necessary because unless these controls are removed, market forces cannot operate freely and the intended efficient resource allocation will not be achieved.

Water transfers are not restricted as such, but the restriction on tradable water entitlement impedes water transfers. Theoretically, inadequately defined water rights and unclear provisions for water markets will not facilitate transfers. Prior to water transfers taking place, the parties involved must have entitlements and a market to trade entitlements. Van der Merwe (2000) revealed that transfers are not objected to, but serious limitations in the process of transferring water seemingly discourage transfers. Limitations like canal constraints, the maintenance of canals at lower operation levels, losses encountered from evaporation, seepage and leakage (where losses are higher for a user downstream) are still prevalent. Also prior to any transfers, activities such as economic, social and environmental impact studies must be conducted to ensure that transfers do not have any negative effects. It can thus be said that water transfers are not restricted, but the restriction on tradable entitlements and lack of readily available information on socio-economic and environmental studies remain the main contributors to the vague transfer arrangements.

Managing scarcity by augmenting supplies is increasingly difficult due to limitations in resource endowment, increasing cost of developing new sources and transfer schemes as well as water quality problems. Mechanisms for demand management are therefore gaining recognition worldwide. It is strange to find no explicit institutional provision for demand management. This lack may pose a serious threat to water security. The demand management effort initiated by the Directorate of Water Conservation and Demand Management of DWAF, and documented by the Department of Water Affairs and Forestry (2000a and 2000b) is however complimented.

In summary, in addition to deviating from current international water institutional trends, the factors mentioned below fall seriously short of an ideal institutional arrangement that will lead to water security. These factors include:

- excessive government control of water management institutions;
- bureaucratic consented water re-allocations;
- administratively set pricing mechanisms;
- lack of appropriate arrangements to facilitate tradable entitlements (e.g. defining exclusive rights to entitlements);
- discouraging and unclear water transfer arrangements; and
- lack of definitive institutional provisions for integrated demand/supply management.

Thus the need for an alternative institutional arrangement that will augment the current provisions to address the above crucial issues becomes imminent and must therefore be pursued. The need for such a framework is expressed in the Department of Water Affairs and Forestry (2000c) pronouncement, which clearly mentions that a new institutional framework will be required to accommodate the daunting task of full decentralisation of water management. It is essential that South Africa be brought into context with the generic institutional framework depicted in Figure 3.3. With the specific goals of the generic framework clearly stated, the goals of the NWA will be revisited to expose the linkages.

The purpose of the NWA is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in a way such that:

- basic human needs of present and future generations are met;
- equitable access to water is promoted;
- results of past racial and gender discrimination are redressed;
- efficient, sustainable and beneficial use of water in the public interest is promoted;
- social and economic development is promoted;

- provisions are made for growing demands;
- aquatic life, ecosystems and biological diversity are protected; and
- international obligations are also met.

In the South African context therefore, attainment of allocation efficiency would mean that adequate provision is made to meet international obligations; equitable access to water by all water use sectors is achieved; and that in-stream use to protect ecosystems is catered for. An efficient allocation system will also redress results of past racial and gender discrimination.

Allocation efficiency complements economic efficiency in the sense that water is transferred from low-value uses to high-value uses as appropriate prices are attached to the resource. Appropriate prices in the market will result in reduced consumption and consequently savings in resource costs. Savings incurred under the right price for the resource will exceed the loss of welfare from lower usage, meaning economic efficiency is achieved. This does not deviate from the South African government's goal of promoting social and economic development, which is linked to the efficient use of a resource.

This framework clearly distinguishes social equity allocations (i.e. allocations or reallocations that take place through administrative devices in order to serve social needs) that cannot be achieved by market means, from general equity allocations, which can easily be achieved by market reallocations. The social equity goal is in line with the government's goal of meeting human needs for both the present and future generations. In addition, addressing this equity concern through the appropriate mechanisms will promote efficient and sustainable use of the resource, which again is one of the goals spelt out in the NWA. If the goals stated above are achieved, in a broader sense it will be relatively easier for water users to make better investment decisions, thereby facilitating economic activity, and social and economic benefits being derived optimally within a secured water economy.

The next chapter will investigate and evaluate other institutional arrangements and select a possible alternative that will be suitable for South Africa under the current circumstances, with the potential to eliminate or reduce the above limitations and improve the efficiency of water resource allocation and use.

3.7 CONCLUSION

International experience continues to indicate that use of water right markets to allocate water is generally superior to administrative allocations. However, administrative allocations score better in terms of equity, political and public acceptability in South Africa. With equity, efficient and sustainable use of water as the major objectives of the NWA, a blend of well-established water markets subjected to a limited and specific degree of government intervention may be the best institutional option (see Figure 3.3)

To promote efficient resource allocation in the short or long term for countries, like South Africa, who are vulnerable to water scarcity, it is important not to select institutional arrangements that will increase uncertainty. On the whole, provisions in the current NWA are positively geared towards addressing most of the traditional water sector concerns, such as social equity, ecological and financial sustainability, meeting legitimate requirements of neighbouring countries, efficient allocation and sustainable use of water resources.

This analysis re-emphasised that current provisions, if effectively implemented, could improve the capability and performance of the water sector. However, issues regarding water entitlements, duration and renewal of permits, mechanisms for transferring water, pricing and reallocation of water require adjustments if the objective of economic efficiency in water use is to be achieved.

If they remain unattended to, the gaps exposed in the current NWA through this evaluation may lead to inefficiency in water allocation and use. The following suggestions would therefore require serious consideration.

In South Africa, the policy of market allocation and privatisation, accompanied by state protection of emerging farmers, urban domestic users and the disadvantaged, is necessary. This can be done through a policy of demand, rather than supply side subsidy (i.e. the poor pay the same price but get lump sum subsidy to cover their excess water bills, as practised in Chile). This approach will hopefully resolve the conflict between the economic goal of full cost recovery and the social equity goal of supporting the underprivileged.

Concerning the duration of water use entitlements, some form of long-term and flexible lease arrangement that respects project life spans and can be re-negotiated after a reasonable number of years, may be necessary. Furthermore, a reasonable guarantee for renewal of permits has to be provided and institutionalised.

As a matter of necessity, all the above arrangements must be explicit and exclusive to the permit holders and enforced by law, as these conditions are prerequisites for water market operations.

Regarding markets for water in South Africa, their development and establishment must be pursued vigorously. Factors that are most likely to impose external costs on the local economy as a result of trading entitlements, as feared by the state, need to be studied well and appropriate means must be sought to reduce or eliminate them.

While involvement by Government in addressing social equity needs is important, more elaborate research must be conducted on how best to achieve economic efficiency and social equity simultaneously. Although the scarcity value of water is increasing, the politically rooted system of public provisions seemingly insulates the water economy from the influence of actual market forces, possibly due to the weakness of water markets regarding equity. Allocations to address social equity in particular have to be safeguarded by the public sector through regional allocation mechanisms.

Even though the provisions for water charges cover capital costs, cost of water management, conservation, operation and maintenance and research, the administrative mechanisms, which are in place to carry them out, are very unlikely to be efficient and would require revision.

The administrative price system that takes precedence over pricing via auctions, or water markets, requires further evaluation before it becomes institutionalised fully. Preferably, a market oriented institutional arrangement, which facilitates integrated demand/supply water management and makes provision for shadow prices (which are good estimates of opportunity cost) to be calculated, must be investigated and adopted if found useful.

In general water markets induce water users to consider the full opportunity cost of water when making water allocation decisions. Thus in South Africa, consideration of the full opportunity cost is a step in the right direction that will hopefully provide incentives to increase the economic efficiency of water use, especially in the agricultural sector. This will be achieved through the use of less water on a given crop, investment in water saving technology, shifting of water applications to more water-efficient crops, changes in crop mix to higher valued crops and transfers of water to higher valued non-agricultural uses. The actual magnitude of efficiency gains for the country will be determined by the degree of water scarcity and the effectiveness of institutions and the infrastructure that are in place.

The strong equity concerns about water markets in South Africa cannot be ignored. Water being vital to life as well as to livelihoods, strong social norms will always argue against its being treated as a simple marketable commodity. Pursuing efficiency through market allocations alone may not be politically or socially acceptable in South Africa if equity considerations are not met. For example, if a water user, by selling his/her water right jeopardises the livelihood of a certain group, or an emerging or small-scale farmer's position is compromised, water markets are likely to encounter opposition. But for South Africa, the possible negative equity effects of water markets can be mitigated through appropriate policies. From a liberal market viewpoint, one alternative is to use market-based allocations, combined with reduction in the massive capital and operating subsidies on irrigation and water supply, which usually favour better-off producers and urban consumers. This would possibly release budgetary resources to target water subsidies to the poorest sectors of the population in both rural and urban areas.

CHAPTER 4

ALTERNATIVE WATER INSTITUTIONAL ARRANGEMENTS FOR SOUTH AFRICA

4.1 INTRODUCTION

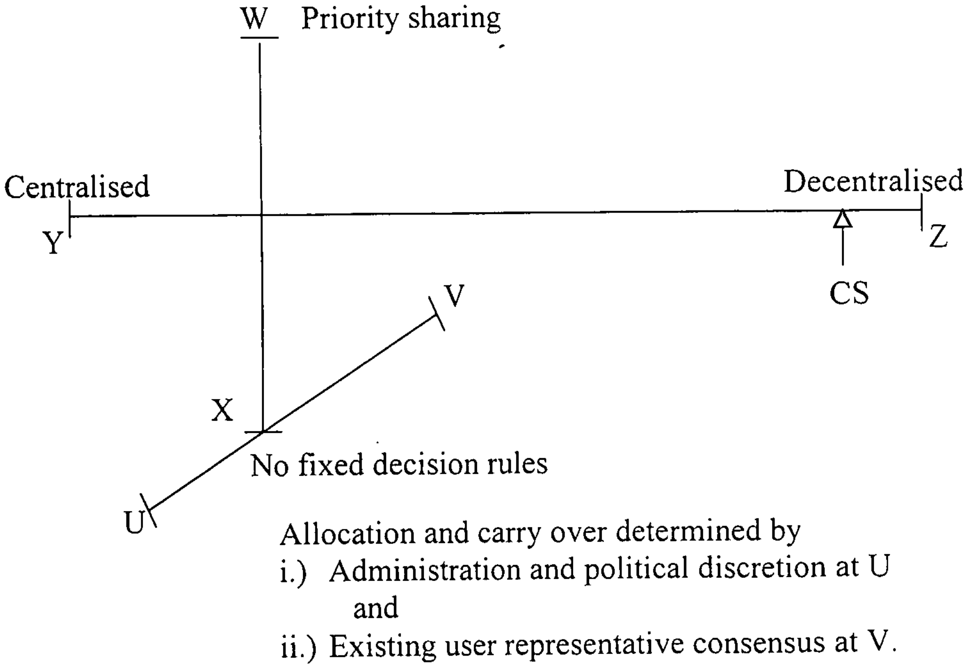
The factors discussed in the previous chapter highlighted possible gaps in current South African institutional arrangements. Efficiency of water resource allocation, use and transfers is seriously challenged and the consequences for water security and economic sustainability are imminent. The new South African Water Law truly has an objective of correcting existing inequalities in the water sector and defining a framework, which may promote decentralisation, market-based allocation and full cost recovery (Department of Water Affair and Forestry, 1997). It remains questionable whether the reform proposals can be instituted in their original form without much political compromise. Saleth and Dinar (1999) noted some key challenges facing the South African water sector pertaining to the implementation of these proposals. These include:

- Resolving the conflict between the economic goal of full cost recovery with the equity goal of supporting the underprivileged;
- Developing strong Water User Associations (WUAs) as an organisational basis for water distribution, system maintenance, cost recovery, water transfers and water distribution;
- Enhancing the regulatory and monitoring capabilities of DWAF for establishing permit-based water allocation;
- Modernising existing projects to allow volumetric allocation and improve delivery efficiency necessary for the use of the water permit system;
- Building technical and information capacity within the water sector; and
- Achieving a high degree of co-ordination not only among various layers of water administration (both existing and proposed ones), but also among various levels of government.

All the above challenges certainly create the potential for conflict and inefficiency. The need to seek solutions to these problems is urgent and critical. While seeking solutions to these challenges it is imperative to investigate other alternative institutional arrangements, particularly those that may offer more opportunities for effective water allocation and management, and be able to address some of the current challenges and pose fewer or no new ones. In this chapter, an alternative institutional arrangement will be selected from a possible set of arrangements. First, the best alternative from the set will be selected by comparing the advantages and limitations offered by each type of arrangement. The alternative chosen will then be proved from theoretical viewpoint as the most appropriate alternative. The system developed in the previous chapter to evaluate the current South African Act will be useful in this regard.

4.2 ALTERNATIVE INSTITUTIONAL ARRANGEMENTS

In Dudley (1990a), institutional arrangements for allocating water among users was categorised dimensionally as shown in Figure 4.1.



Allocation and carry over determined by
i.) Administration and political discretion at U
and
ii.) Existing user representative consensus at V.

Figure. 4.1 Spectra of water resource decision-making

Source: Dudley, 1990a

Institutional arrangements generally vary from centralised bureaucratic management approaches to completely decentralised market-based system. It is interesting, therefore, to note that the dimensional representation of institutional arrangements as in Figure 4.1 caters for a myriad of possible institutional arrangements. Within the scope of this study, only selected alternatives will be chosen and discussed.

Line YZ (horizontal axis) illustrates a continuous spectrum of centralised bureaucratic administrative procedures to a completely decentralised market system. Nations are shifting towards the Z end of this axis, as reflected in global trends on institutional arrangements. The actual position on the axis is country specific and depends on the needs being addressed by the country's water sector.

Close to the "centralised" end Y of this spectrum, is the line WX (vertical axis), representing a range of centralised types of water allocation. At W, for example, water management is characterised by pre-determined set of decision rules, and no decisions are made without such rules, as in Priority Sharing (PS). At X, on the other hand, decisions are made through time in the absence of such rules. At point X lies another range UV, illustrating decision making by different combinations of administrative or political discretion, and consensus among representatives of existing users. That means a group consisting of water supply authority representatives and user representatives makes periodic allocation and reservoir carryover decisions. This is referred to as Discretionary and Consensus Allocation (DCA), (Dudley, 1990a).

It would appear from these chosen institutional arrangements that CS and DCA have most advantages pertaining to efficient allocation and transfer of water resources. These two also allow for flexible water user management decision making. Under these arrangements, water and water rights would move from less efficient to more efficient users. Rights to quantities of water with specific probabilities of supply at specific times would be the same in each case (Dudley, 1990a).

Table 4.1 Characteristics of four diverse institutional arrangements

Type of institutional arrangement	Characteristics	Outcome
Priority Sharing (PS)	Predetermined decision rule	- Makes room for users or their agents to estimate water supply probabilities. - Efficient short, intermediate and long term demand-side decisions. (Complex to achieve as stream-flow data must be integrated with rules)
Discretionary and Consensus Allocation, Political. (DCA$_{U}$)	Unpredictable administrative or political decisions	- Users management decision making is impaired, (especially long term) transfers inclusive.
Discretionary and Consensus Allocation, User Representatives. (DCA$_{v}$)	Decisions made solely by user representatives with similar water supply reliability preferences.	- Water supply reliability - Allows efficient demand-side decision making. - Accurate forecasts of allocation and carryover decisions by representatives - Allows estimation of water supply sufficiencies.
Capacity sharing (CS)	Completely decentralised and the role of market is paramount and supreme.	- Pure market allocation of water in the short term and rights to water in the long term. - Efficient water allocation. - Efficient water user decision-making.

Source: Derived from Dudley, 1990a

Comparatively, Capacity Sharing is preferred to DCA as that politicians, administrators or user representative groups could change the number of users and or the mode of sharing water under DCA but not under CS. This would mean a change in long-term security of water supplies to existing users under DCA, because their supply reliabilities could be altered without the amount of compensation they would regard as sufficient. Unlike DCA, individual user rights under CS would provide perpetual security of tenure to reservoir inflows and reservoir capacity which they would only forgo by selling at a price attractive to them (Dudley, 1990a).

From an institutional economic viewpoint, welfare implications are crucial for optimal as well as efficient allocation and use of resources. Under CS, optimal and efficient allocation of water is achieved; in addition, the water user enjoys the privilege of managing supply and demand, thereby reducing risk to the barest minimum and hence maximising welfare. The next section discusses the origin and the concept of CS.

4.3 CAPACITY SHARING (CS) AS AN ALTERNATIVE INSTITUTIONAL ARRANGEMENT FOR SOUTH AFRICA

Capacity sharing is a new concept in South African Water Resource Management circles. Dudley and Musgrave (1988) first developed this water management concept in 1985 at the University of New England in Australia. This innovative means of allocating water has the capacity of overhauling the current more centralised approach to water management completely and transforming it into a decentralised form, characterised by efficiency and optimal use.

In this vein, the concept must be understood by all stakeholders in water management, particularly water users, water policy makers, administrators and relevant institutions in the water industry. Using a wide range of available literature, this chapter defines CS broadly and represents the concept schematically. It also highlights the main features, the advantages and disadvantages as well as practical experiences of its implementation.

4.3.1 Definitions

Dudley and Bryant (1995) defined CS as an institutional arrangement and property rights structure for allocating water among multiple users of water resource systems, which include storage reservoirs. It provides each user or group of users of reservoir water with perpetual or long-term rights to a percentage of the reservoir inflows and percentage of total reservoir capacity or space in which to store those inflows and from which to control releases.

Capacity Sharing, according to Doertenbach (1998), is a complete equitable fractional allocation system that is backed by legislation. Under the system, water rights (permit), for a combined irrigation scheme or other multi-participant reservoir is assigned a single priority date, which is shared by all the participants, with each of the participants in these schemes entitled to a fixed percentage or fraction of the water to which a parent water right is entitled.

Scott (1994) defined CS as an innovative institutional arrangement for the management of surface water resources on a total catchment basis. In this explanation, CS is described in the context of one's own reservoir on one's own stream. Thus, CS is a concept relating to space, a space in which the owner can store his inflows and manage that storage in a way the owner sees fit.

Lang (1999) perceives CS as a water management system, which enables water users downstream of a reservoir who share one source of surface water (river) and one storage work (a dam) to act independently from each other and as if each one of them was the owner of a small catchment and a little reservoir.

All contributors to the explanation and definition of the concept of CS seemingly converged on one point (i.e. allocation of water to diverse users of a water resource system, with users in turn managing their own share of allocation). Even though there has been significant publicity for CS to date, it is common to come across people who missed the point or failed to understand the basic concept underlying CS or confuse these with current thinking or methods of water allocation. Often, people remain focused on the volumetric allocation concept or cannot think in terms of dividing up water without including the current amount of water in the reservoir (Scott, 1994). To lighten this misconception, the schematic representation of CS is presented in Figure 4.2.

As shown in Figure 4.2, the total capacity comprises a single or multiple reservoirs, a defined section of a river or group of rivers linked together. Capacity shares are either bulk or retail. Bulk shareholders will be nations, provinces, industry and the like, with fewer incentives for efficient use of water and related resources. This is probably because these shareholders are not final consumers. Households, firms, farms or any end user can own retail shares. The retail shareholders have higher incentives for efficient use of water since all resource management decisions are made by them.

Apparently, CS is feasible under multiple purposes. In all cases the relevant water authority would obtain capacity shares by market or non-market means and make releases to users over time as desired.

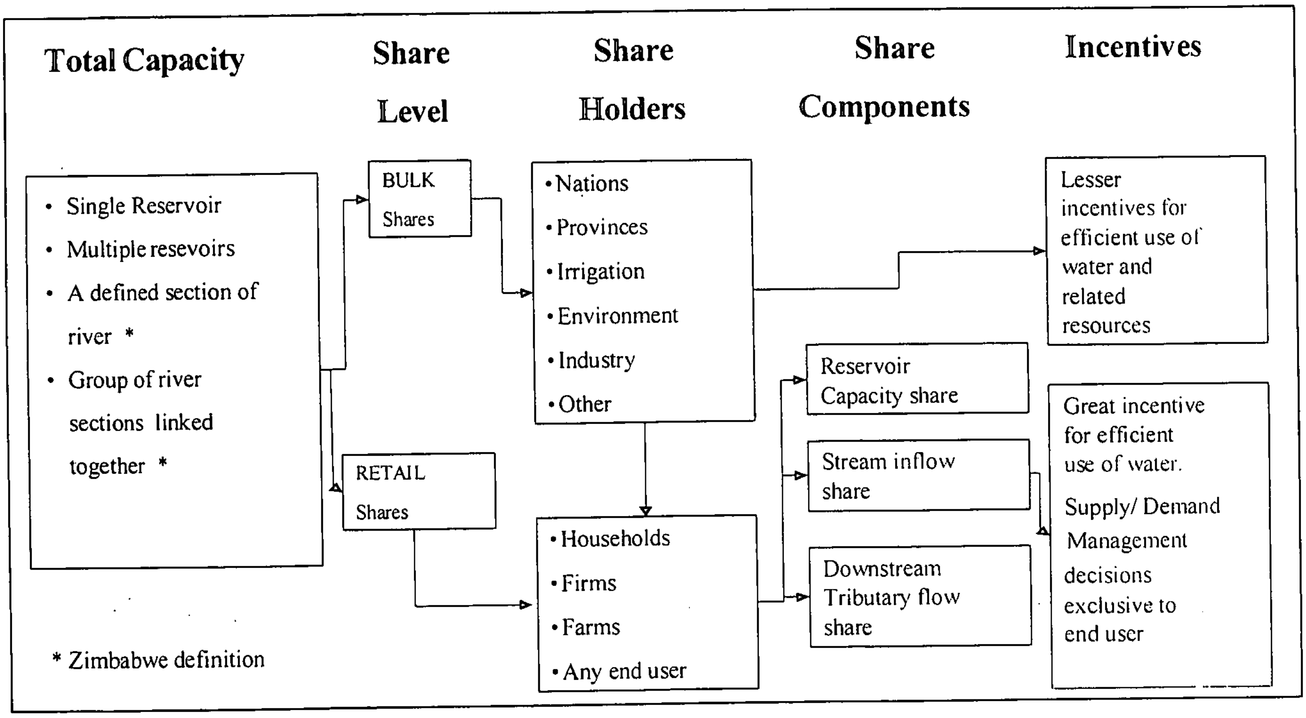


Figure 4.2: **The concept of Capacity Sharing**

It is necessary to stress that CS in not applicable to or has limited applicability for any reservoir use in which the contents of the whole reservoir affects the returns to the use. This is the case for hydropower, where the reservoir water level affects the "head" or pressure of the water and thus the return per unit of water released through the turbines. Similarly, the value of lake surface recreation usually depends on the volume in the total reservoir, including other users' capacity shares.

A preliminary analysis of the feasibility of CS (Dudley, 1988) stipulates that capacity sharing, coupled with market transferability of shares by auction, will provide all water users with a greater security of tenure in water use compared to other water allocation alternatives. For example, as urban and environmental management demand increases over time, irrigation users need not fear that their individual reliability of supply will change without them deciding to sell their shares at market value. Similarly, urban and environmental users are aware that their shares can always be expanded as demand increases, by paying the market value for extra shares. More advantages of using CS can be derived from its features, and will be discussed in the next section.

4.3.2 Features of Capacity Sharing

This form of institutional arrangement of water sharing has certain distinguishing characteristics without which it ceases to be functional. Below are some of the essential features.

4.3.2.1 Water User Rights

CS relies on water use rights, which are explicit, exclusive to shareholders, exchangeable or transferable and enforced by law. Such rights form an excellent foundation for water markets for water already in the reservoir or streams, or for long-term rights to future water.

In actual fact, the original formulation of CS specified that these rights be held in perpetuity, so that holders would make correct long-term investment decisions whenever opportunities arose through time (Dudley and Bryant, 1995). Other schools of thought, according to Dudley and Bryant, also suggested that rights should not be held in perpetuity but be held as some form of long-term lease which would come up for re-negotiation after a number of years notice. The essential point is that the period of tenure be sufficiently long to encourage users to incur the level of investment required to maximise efficiency

Certain features of CS also came to light in an attempt to identity the criteria by which water allocation institutions could be assessed. The criteria as documented by Howe et al. (1986) and reported by Scott (1994) are as follows:

- Flexibility, so that allocations can respond to changing circumstances (for many purposes flexibility may only be necessary for marginal allocations);
- Security of tenure, so that users have sufficient confidence in continuous use to make optimal investment and maintenance decisions;
- Payment by users of the correct and full cost of the water they use;
- Predictability, so that the consequences of decisions do not cause unexpected surprises; and
- Fairness, so that users do not impose uncompensated advantages or disadvantages on others.

A system of water rights that satisfies these criteria would be non-attenuated (Dudley and Bryant, 1995). This implies that the right cannot erode through time, either by taking it away or reducing its scope. It can thus be understood why CS is a non-attenuated water property right, which is explicit, exclusive, enforceable and transferable. Non-attenuating means a user cannot lose any of the right without losing what is perceived to be adequate compensation (Scott, 1994).

In the context of urban water use, other features of CS have been identified by Dudley (1990b) and a summary is presented below:

- Water in a CS reservoir would become a private property resource rather than a common property resource. Therefore, users would have an incentive to conserve water when it is in short supply relative to requirements, and to use it freely when it is plentiful since opportunity cost would be taken into account.
- CS would provide equitable rationing in times of shortage.
- CS would have the consumption-reducing advantages of highly fluctuating water prices without producing a destabilising effect on the consumers' finances.
- Supply authorities would stabilise net revenue, as "user pays" would apply to water collection and distribution facilities rather than water use as such. CS would also allow a high degree of separation between the allocation and revenue raising roles of water pricing.

The above listed features will apply to other uses, such as irrigation, as well.

One other attractive feature of CS is that it can be implemented in isolated "river sections" or reservoirs as and when required, with the degree of complexity determined by local requirements. River sections can be linked as and when conditions dictate, provided the probabilities of stream-flows can be defined as accurately as possible. This can be achieved where no upstream users exist or where the probabilities of volumes used by upstream users can be derived accurately. Management and measuring requirements can be refined as required over time. The system can and will evolve naturally as competition for available water increases. Community-based Water User Associations, using guidelines provided by Catchment Management Associations, found this allocation system to be user friendly (Doertenbach, 1998).

4.3.2.2 Water Markets

An integral part of CS would be the establishment of markets for water users to trade water. Water markets will operate at two levels under CS:

- to transfer water already in storage, stream or channels and
- to transfer long-term rights to parcels of shares in reservoir capacity and stream-flows.

The water market ensures that water users cannot lose water rights to other users or government without market compensation, which they deem to be adequate. Thus, the water market provides two very important ingredients for efficient and sustainable use of water and associated resources in the long term under CS. These include *security* of tenure of supply rights of known reliabilities to users and the *flexibility* for water resources to move into alternate uses as conditions change (Dudley, 1994).

The security of entitlement to water currently in the user's reservoir coupled with the estimates of the probability of inflow, place the user in a position to decide on the quantity of water to buy or sell at any point in time. A water market spot price would also reflect current supply and demand conditions, while possible futures markets would also allow users to reduce risk further (Dudley, 1990b).

4.3.2.3 Security

CS, by its unique nature of holding rights in perpetuity, offers considerable security to participants. As envisaged by Dudley and Bryant (1995), the only way a CS share can be removed from a shareholder would be via market transfers, unless the individual broke laws that protect natural or built assets. Should society decide that water resources were needed for an existing or new use, the specific body has to enter the relevant market, be it reservoir capacity shares, reservoir inflow shares or downstream tributary shares, and purchase them from whoever values them least.

A unit of water in a reservoir, unlike land, is indistinguishable, thus under no circumstances will a situation arise where a particular shareholder's share will be at risk of being needed specifically (Dudley and Bryant, 1995). This provision under CS guarantees fairness absolutely and protects the beneficiary's shares. Furthermore, in the event of part or all of a particular participant's share being required for a potential use, government would be obliged to assume the shareholding and pay compensation, for which market prices should serve as a good guide. CS therefore offers shareholders peace of mind, knowing that any user or institutional interventions outside market operations cannot deprive them of their shares without adequate compensation.

4.4 MERITS AND DEMERITS OF CS

To clarify the usefulness of CS, Dudley and Bryant (1995) discuss the benefits that water management institutions will derive in adopting CS, also pointing out the few disadvantages that may result.

4.4.1 Merits

- Capacity sharing can apply to all water user groups, including irrigation, urban, stock and domestic, and environmental uses such as in-stream flow or off-stream wetlands, energy and industrial users.
- As mentioned earlier, CS offers specific rights to proportionate shares. In addition, these shares are not modified by the administrative or political process in the form of aggregate, common or public carry-over rules, or rules governing private carry-over under continuous accounting.
- Under CS, supply and demand of the water resources are managed better. The integration of demand-side and supply-side management by shareholders with the

aid of management consultants will enable water users (especially irrigators) to determine their reliability requirements. As a result, all types of water users are able to plan ahead to match uncertain supply with uncertain demand, according to their reliability preferences.

- Computer simulation and optimisation models used in CS are tools that integrate both supply and demand management decision-making in irrigation. These models facilitate good short, intermediate and long-term management decisions based on supply and demand conditions. CS also promotes decentralised integration of supply and demand management of water by users. The individual users can conduct their own management with virtually no interference from others, as long as the rules are obeyed. Participation in the water market is not obligatory as users may interact with others only when it is deemed beneficial.
- One other major benefit of CS is the potential for markets to separate the various roles of water pricing. Water pricing plays three main roles;
    - to communicate to each user what the highest value of water to other users is (i.e. its opportunity cost), now and in the future;
    - to recover at least some of the operating and capital costs of the water supply and distribution system; and
    - to determine when the current value of water has risen to the point that supply supplementation is called for.

CS allows water marketing to convey the current opportunity costs of water, thus eliminating the role of centralised pricing. Distribution and reservoir costs can be charged on a fixed annual basis, where each user's charge depends on the size of the reservoir capacity share held and their use of the distribution system (these two costs will not be directly related to water use).

The best time to increase the size of a reservoir or build a dam is also relatively easy to identify under CS, as this occurs when the aggregate value of bids for shares for reservoir storage capacity plus a government subsidy, if available, equals or exceeds the construction costs. (Dudley and Bryant, 1995; Dudley, 1996). Prior to construction and after technical feasibility has been achieved, capacity shares are floated at markets. Water users will purchase shares in the reservoir capacity, reflecting what they perceive to be the value of the share in that reservoir (economic viability). If sufficient value is placed on the shares and all the shares are sold, then the property is paid for (financial viability). This means the impending project is both economically and financially viable. Environmental considerations can be incorporated in the same way, by not allowing a hundred per cent of the inflows to the reservoir, thus retaining a portion for the in-stream flows. With financial, economic and environmental tests passed, the socio-political test will also be passed (Scott, 1994).

4.4.2 Demerits

The immediate disadvantages of CS, according to Dudley and Bryant (1995), are threefold. They are:

- Sharing transmission losses resulting from evaporation and seepage. Transmission losses vary according to the distance water must travel and the volume of water accompanying it in the stream. But reservoir losses would be shared according to the proportion of shares, which contain water in them (i.e. when shareholders have zero balance in their accounts, no losses would be incurred). The need for, and complexity of attributing these losses to individual accounts is however a short-term disadvantage which in the long term encourages greater efficiency in the form of reduced losses as a result of individual user or user group accountability.
- In addition to reservoir and tributary inflow capacity shares, each water user would also require a share of the "delivery capacity" of the distribution system (i.e. the peak flow capacity of water courses and channels) and the capacity of headwork storage to release water (i.e. the maximum rate at which water can be released). Both channel capacity limitations and reservoir maximum attainable release rates may mean that all shareholders may not be able to release water from their reservoirs exactly at the same time and at the rate they prefer.
- Problems of obtaining accurate estimates of supply system losses, as regular reconciliation of loss estimates with actual losses are necessary.

The last two of these points apply to Dudley and Bryant's study area because there the natural river and creek are used as the delivery system in contrast, the study area of this work uses a special built concrete laid canal. Thus these two points apply only marginally to this study.

From these general advantages and disadvantages it is worth investigating the specific benefits South Africa is likely to derive from adopting CS.

4.5 BENEFITS OF CS FOR SOUTH AFRICA

According to Winpenny (1994), reallocations through administrative devices such as quotas or edict will not necessarily accrue to uses with higher economic value, though the reallocations may serve a social purpose. CS as a reallocation mechanism will save water managers the trouble of having to administer rigorous quota systems, which in the end may not achieve the stated objectives.

Table 4.2: Relative benefits of administrative water allocations and water markets

Criterion	Water Markets	Administrative allocations
Flexibility	X	
Security of tenure	X	
Real opportunity cost	X	
Predictability	X	
Efficiency	X	
Equity		X
Political and public acceptability		X
Efficacy		X
Administrative feasibility and sustainability	X	

X = superior performance

Source: WRC Report No. KV96/96, of 1996

Recorded in WRC Report Number KV96, (1996) as documented in Table 4.2, issues regarding flexibility, security of tenure, real opportunity costs, efficiency, predictability and sustainability are addressed more satisfactorily by using water market mechanisms. On the other hand, administrative allocations are preferred due to political and public acceptability, efficacy and equity (WRC, 1996).

CS is dependent on water markets for its success. The strengths of water markets listed above therefore confirm the advantages CS can offer the South African Water Administration.

As a significant step towards decentralisation, it is reiterated that water users, through CMAs and WUAs, play a significant role in planning, managing, decision-making and administration (Department of Water Affairs and Forestry, 2000a). CS will facilitate a faster decentralisation approach to water management, as retail capacity shares will be monitored or administered fully by WUAs, while all on-farm water use or carryover decisions become the responsibility of the water user.

If CS is adopted in South Africa, CMAs will be involved in water management at the bulk level (Figure 4.2). Being bulk managers, CMAs will be responsible for safeguarding equitable allocations to bulk shareholders and ensuring compliance with all rules and regulations.

CMAs will progressively monitor and measure stream inflows, rainfall into the reservoir and record all losses due to evaporation, seepage and reservoir overflow spills. These records, together with ordered releases by each of the bulk users, will assist CMAs to update shareholdings of users. Computer printouts of these records (water accounts) reflecting user's reservoir capacity will be sent to holders of bulk shares periodically. One other major role CMAs can play under CS in South Africa is protecting the interests of the large group of currently emerging small-scale farmers. This group of farmers may not have the capacity to operate individual retail shares as large commercial farmers. CMAs will therefore have to secure a bulk allocation for this emerging group and delegate WUAs to carry out the administrative, supply-side as well as demand-side management decisions on their behalf, until they attain the required skills to integrate this supply and demand management themselves.

WUAs, on the other hand, will operate at retail level (Figure 4.2), with responsibilities similar to those of CMAs, who oversee bulk shares, but in this case a large number of smaller shareholders will exist. Essentially WUAs will:

- administer capacity share accounts;
- electronically distribute account printouts and any relevant information to groups, individuals or group representatives;
- play a vital role when a combination of retail/bulk shares are required to address the needs of the emerging or small scale farmers;
- be responsible for training water users, as this will empower them to operate their shares effectively and efficiently.

Households, firms or any end users under CS will enjoy full benefits of learning to manage their own demand and supply overseen by the WUA. It is important to mention that since all individual users have a say in the WUA administration, no one is likely to be undermined. Equity issues will be addressed and the concerns of emerging and/or small-scale farmers cannot be compromised. Small-scale farmers, being registered members of WUAs, can no longer be marginalised, because under CS, once the right to water use is granted, security of tenure is guaranteed and the concerned water users can only lose or have their use rights challenged when a rule or regulation is flouted deliberately.

Reliance on a considerable period of hydrological data (especially stream-flow) in developing the CS model provides adequate information on samples and sequences of events (Dudley, 1992), which are much needed in integrated demand and supply management of water resources, as echoed by DWAF. Water conservation and demand management strategy for the agricultural sector emphasise best use and allocation of existing available resources. With Capacity Sharing modelling techniques, it is possible to provide tools for measuring reservoir capacity shares, which will assist users, participation in the market for reservoir water. The next section will review how flexible the current institutional arrangement of South Africa is, in order to accommodate CS.

4.6 CAPACITY SHARING AND THE NEW WATER ACT OF SOUTH AFRICA

From the various definitions of CS above, it is clear that CS only thrives when specific requirements pertaining to property rights, water marketing, transfer mechanisms or arrangements, pricing techniques and general administrative approaches are met. The provisions in the NWA regarding these issues must be revised to ascertain whether the current institutional provisions are adequate or have any prospects for the adoption of CS.

Capacity sharing specifies that water rights be non-attenuated in order to guarantee security of tenure. This condition is compatible with international trends and ideal institutional arrangements regarding property rights. Water users need at least one of the following two things in order to be encouraged to make sufficient investment to achieve efficient use of water and other resources;

1. Have secure tenure to their share of reservoir capacity and inflows for a long period of time.
2. Secure knowledge that they will be compensated at the current, free market value their entitlement to 'their' capacity share and inflow share The evaluation of South African institutional arrangement for water management reflects serious inadequacies in the property right provisions. Section 4(3) of the NWA, referred to in Appendix C, spells out the property rights arrangement. The effective five-year licensing period and the absolute authoritative stance of government regarding issuing/renewal of permits, falls significantly short of capacity sharing requirements and will therefore require adjustments. Market trading of entitlement is also seriously restricted, as in Sections 26 and 45 of the NWA.

Water transfer mechanisms are all purely administrative and all arrangements to this effect are also under ministerial control. This excessive power vested in the minister generally with regards to sales and transfers of water resources does not augur well for the establishment of CS.

Under CS, water markets will determine the prices to be used to achieve efficient re-allocation of water. Any administrative interference will seriously compromise resource allocation to their most efficient uses. Sections 56 – 60 of the NWA and Department of Water Affairs and Forestry (1999b) endorsed administrative approaches to pricing which is highly incompatible with CS. These limitations do not apply to CS alone but also apply to other alternative institutional arrangements. The limitations should therefore not be seen as a 'dead end' for CS.

Provisions in the NWA for the establishment of CMAs and WUAs and the progress made thus far in this regard opens the door for a more relaxed water management environment where CS is most likely to be considered. The extent of delegation or devolution of powers to these institutions will be crucial if CS is to be adopted

In Zimbabwe, despite the fact that water rights are not perpetual and restrictions are placed on sale of water entitlements, with a considerable amount of power vested in the minister (like in South Africa), CS seems to be working well (Lang, 2000). It can be explained as follows. The owner of a storage space (A) does not need to have a right to sell water in order to benefit from other people's interest in renting storage space. The holder of a permit (B) without storage space, by virtue of the water permit, is entitled to water (a share of water generated during a defined period) and therefore needs a "vehicle" to transport water in time (from the wet to the dry season). Essentially A can only lawfully use water in the dam if he/she has a water permit. If A does not have a water permit, he/she is not entitled to store or use water. However, B is entitled to store water in A's dam and use it, provided he/she has rented storage space (purchased the right to use A's storage space) from A. Thus, in the mutually beneficial deal between A and B, no sale of water is involved.

The twenty-year water permit granted by the Catchment Council (CC) in Zimbabwe poses little threat to CS. Lang (2000) believes that this is a reasonably long time in the life of most businesses. It is also believed that if a user made good use of water in the past it is highly unlikely that the CC will turn down the application when it comes up for renewal. Thus, from a permit holder's point of view, there should be no reason to be afraid of permit cancellation when water is used properly. In areas of considerable competition, permits may be reduced by 10 per cent, but this is unlikely to bring about the downfall of a business. Currently the CC is considering institutional amendments to phase in renewals five years ahead of expiry of permit. This will enable the CC to indicate to the permit holder whether the permit is likely to be renewed, reduced or withdrawn. For owners of storage space, the limited validity of water permits not a problem either, because if the permit of one client is withdrawn, chances are that another user will step in and be interested in renting the same storage space.

Concerning ministerial powers in Zimbabwe, water managers would have preferred a reduction of powers of the minister, but focused on Section 38 of the Zimbabwe Water Bill instead, which opened the door for more market activity. In that provision, the CC can allow the sale of permits after consultations with the secretary. It is expected that the secretary will only be involved if this is being done for the first time. Once a CC has convinced the secretary that the procedure is worthwhile, subsequent decisions will be placed in the hands of the CC (Zimbabwe National Water Authority Act, 1998). Successes to date in Zimbabwe regarding Capacity Sharing are encouraging to the extent that this mode of water management is real and can be applied successfully in South Africa as well.

After the concluding remarks, the next chapter will discuss Capacity Sharing modelling procedures and how vital information can be derived for the relevant water management institutions in their quest for optimal allocation and efficient use of water.

4.7 CONCLUSION

The study of diverse institutional arrangements for water management reveals that Capacity Sharing has more advantages compared to the other institutional arrangements studied. CS will serve the needs of South Africa well because of its dependence on water markets, which has strengths regarding security of tenure, predictability, flexibility, opportunity cost pricing and efficiency of water use.

CMAs will enjoy considerable credibility because at bulk allocation level, there is transparency, because CS is a precise, concise and clear mechanism for allocating water through time, even under conditions of uncertainty.

From experience it has been learned that individual user rights under CS would provide perpetual security of tenure to reservoir inflow and reservoir capacity, which would only be forgone by selling at a price attractive to the right holder. Besides, water users are granted the opportunity to manage their shares of reservoir space, reservoir inflow and tributary flows.

Furthermore, from an institutional economic viewpoint, welfare implications regarding optimal as well as efficient allocation and use of resources are crucial. Under CS, optimal and efficient allocation of water is achieved. In addition, the water user enjoys the privilege of managing both supply and demand, thereby reducing risk to the barest minimum and hence maximising welfare. Also there is a great ability for CS address issues of equity and the concerns of emerging as well as small-scale water users. Capacity Sharing therefore has the potential to be the most appropriate alternative institutional arrangement for South Africa and can be used fully or partly to augment current arrangements. The concept of CS should therefore not be viewed as a complex and unworkable water institutional arrangement in South Africa. Adequate provisions should therefore be made for its implementation, at least at the bulk share level sectorally and at retail level for the agricultural sector in a selected catchment, to test its feasibility. The following suggestions become pertinent and worth considering.

- A certain reduction in ministerial powers is necessary, with more powers pertaining to resource reallocation and transfers delegated to CMAs and WUAs. Autonomy of these institutions under appropriate institutional arrangements will lead to a more decentralised approach to water management, which is consistent with Capacity Sharing.
- Concerning rights to water use, long-term right, which is currently an issue in the NWA, could possibly be replaced by long-term leases. These leases can be devised so they don't harm farmers' long-term investments and resource management efforts.
- Market transfer of permits must be encouraged and institutionalised to allow water transfers to most beneficial uses either between sectors or within sectors.
- Institutionally there should be a reasonable guarantee that efficient water users will not lose any part of their permits without adequate compensation.
- The idea of administrative pricing should be discouraged. It might be easier and understandable yet inefficient. Appropriate techniques, like shadow pricing, which is very useful in the estimation of opportunity cost, should be encouraged.

The steps taken by water managers to date, in conjunction with the above suggested institutional adjustments, if implemented, will encourage reallocation of water resources to higher value and more efficient users, which is consistent with the concept of Capacity Sharing and sustainable water use. If adopted, the success of CS in South Africa will depend on strong political will to make it work and the unwavering commitment of CMAs and WUAs, who will need specific management tools or models.

CHAPTER 5

STOCHASTIC DYNAMIC PROGRAMMING FOR SUSTAINABLE WATER MANAGEMENT

5.1 INTRODUCTION

After developing an ideal water institutional framework for sustainable water management, Capacity Sharing (CS) was evaluated as an alternative institutional framework for managing South Africa's water resources in the previous chapter.

Capacity Sharing pivots on dynamic stochastic optimisation to aid decision-making. This is because of the stochastic element fundamental to water supply and demand, particularly in hydrology. The choice of stochastic dynamic programming simulation as a tool for modelling integrated water demand and supply in this study is therefore warranted.

Most water management and planning models, according to (Dudley and Hearn, 1993), fail to integrate fully the management of water supply and demand into a total system within stochastic environment. Dudley and Hearn (1993) reiterate that, where both water supply and demand are stochastic, there is a hierarchy of short, intermediate and long-term decisions to be optimised in order to maximise returns from irrigation water. Dudley (1988) stressed that failure to take an integrated approach can result in reduced regional income, especially under the scenario of water scarcity due to increasing demand.

Against the above background, this chapter considers the adopted Australian CS computer model. Specifically, the purpose of the model, inputs required and outputs to be generated, will be discussed in this chapter.

5.2 SIMULATION OF WATER RESOURCE SYSTEMS

Numerous methodologies from systems engineering, particularly mathematical modelling, have been used over the last few decades for the optimal design, planning and operation of water resource systems. Simulation and optimisation models are the two basic categories of water resources models in water allocation. According to Reca, Roldan, Alcaide, Lopez and Camacho (2000), the two types of model differ significantly. The main difference identified is that "optimal allocation" of water is determined independently for each one-time interval of analysis when a simulation is carried out. On the other hand optimisation models carry out multi-interval analysis on optimal allocation.

The main limitation of these models is, according to (Reca et al, 2000), that the objective functions are not actually economic in nature and therefore do not guarantee optimum water allocation in deficit systems. More often than not, they do not take into account the non-linear nature of economic functions. To overcome these limitations it is imperative to incorporate economic objective functions in water allocation models. Furthermore, the stochastic nature of water resources must be taken into account. This will facilitate the evaluation of the economic trade-off between consuming water in the present against saving it for future dry periods. Optimisation must therefore be extended to a series of consecutive years (Reca et al, 2000).

Cummings (1972), as documented by Dudley, Reklis and Burt (1976), employed LP to estimate optimal acreage of feasible crop activities for a summer irrigation season, and resulting net revenue as a function of quantity of surface reservoir water released during that season. Using historical stream-flow data Cummings (1972) derived probabilities of the changing reservoir levels from one discrete level to another during the year. By using these reservoir level transition probabilities and the functional relationship between net revenue and reservoir releases derived by LP, optimal annual reservoir releases as a function of beginning-year reservoir level were derived by dynamic programming; with maximum expected net revenue being the objective.

Dudley, Reklis and Burt (1976), expanded on Cummings' (1972) work, in short-term management optimising models by introducing a simulation model. This simulation model simulates flows through the reservoir for each of the years of historical flow data available to determine state variable transition probabilities for each season, or sub-stages and adjusts the benefit function from the LP output to cater for water shortages occurring within a season. By using these transition probabilities and benefits, dynamic programming was employed to determine the optimal amount of water to allocate to irrigation during each season (sub-stage) throughout the planning horizon, depending on the conditions at the start of each season. The DP solution yielded a conditional decision rule or policy for each length of planning horizon.

In another application, Yaron and Dinar (1982) combined LP and DP to calculate the optimal allocation of irrigation water over time. A systems analysis approach was used to allocate scarce water during peak season to alternative crops and plots using soil-moisture response functions for the crops. The approach provided an irrigation-scheduling programme for farms during the peak season, taking into account overall farm restrictions and the shadow prices of water and other resources. The results provided a schedule for an optimal allocation of water among crops and over time. The overall approach used two sub-systems. Sub-system 1 (LP Model) maximises farm income. The LP solution yielded a vector of shadow prices. These vectors were incorporated into Sub-system 2 (DP Model), generating new irrigation activities to improve on the LP solution repeatedly until the optimal solution is achieved through convergence.

Decision-making through time is very important in the modelling of natural resource systems, hence the need for DP. According to Dudley (1999), the separation of time into stages or decision intervals, that is, a period of time over which a particular level of control is held constant, results in multi-stage decision processes. The use of DP in such decision processes requires that at each decision point, all factors influencing the response of the system to different decisions must be condensed in the description "state of the system" at each stage. The state of the system is defined by a specific combination of (discrete) values of "state variables".

As documented in Dudley (1999), DP uses the recurrence relation recursively to calculate the optimal remaining returns for each state at stage *n* given the optimal remaining returns for each state of stage *n-1*.

The recurrence relationship is:

$$f_n(i) = optimum \quad [V_n(i,k) + B_n \sum_{j=1}^{J} P_n(i, j, k) f_{n-1}(j) \quad \text{...(Eq 5.1)}$$

Where;

n = number of stages left in the planning horizon or future of interest

n = 1,2...N;

$f_n(i)$ = present value of optimal expected returns (e.g. cost or revenue) over the remaining n stages in the planning horizon given that the current state is *i* and optimal decisions are followed in each remaining stage;

i = discrete state variable combination for the start of stage when n stages remain where i = 1,2,...I;

j = discrete state variable combination at the end of stage when n stages remain and $j_n = i_{n-1}$, j = 1,2...J;

$V_n(i,k)$ = i x k matrix of expected immediate returns (i.e. expected returns in the immediate or just-beginning stage) when n stages remain, state *i* exists and decision *k* is implemented;

$P_n(i,j,k)$ = probability of the system state changing from discrete level *i* to *j* over the stage when *n* stages remain and decision *k* is followed;

$f_{n-1}(j)$ = present value of optimal expected return over the remaining *n-1* stages when the state at the end of the immediate stage is *j* and optimal decisions are followed in each remaining stage; and

B_n = the discount factor for the current stage.

5.3 SIM – DY – SIM COMPUTER MODEL

In this study the use of an optimisation model that is based on economic efficiency criteria is emphasised and pertinent factors such as the state of the resource (water), the returns that would accrue to the water user and how much water a user can release and when, are considered. These issues are vital to the decision-makers involved in water allocation planning.

The SIM-DY-SIM model combines double simulation and Stochastic Dynamic Programming (SDP). It has the potential to integrate water demand and supply, taking hydrological factors into consideration, resulting in water users and water managers taking short, medium and long-term water management decisions fairly easily.

The model is built on a recursive dynamic programme optimisation algorithm, which incorporates a discounting factor for the current stage and the probability of the state of the system changing during stages. It essentially aids decision-making for problems where dynamic and stochastic elements are important in systems that require numerical solutions. It is programmed to combine two computer simulations with dynamic programming. The components and outputs of SIM-DY-SIM are depicted in Figure 5.1.

The basic components of the model are: SIM 1, which receives the inputs, gross margin from the LP, hydrology data from the Department of Water Affairs and Forestry as well discount factor which is calculated by using weighted average cost of capital. SIM 1 performs calculations and gives the outputs which include: the objective function matrix (OFM), which is made up of contributions to the objective function given by following a decision over the immediate stage; and transition probabilities (TPs), which is the probability of moving from state *i* of the resource to state *j* when a specific decision is made in a given stage. The processed information is fed to the DY. The DY receiving these inputs will run a new programme and output the state of the resource, the optimal policy decision to pursue and the present value of expected optimal remaining returns. The optimal policy decisions are fed to SIM 2 as new input. SIM 2 then simulates the effects of using the optimal decisions derived by the DY, giving a wide range of results, like stream flows (SFLOW), reservoir losses (LOSSES), water releases (RELEASES) and farm revenue (FRMREV) among others. CALC is a sub component of both SIM 1 and SIM 2. The heart of CALC is a computer code that must be supplied by the user of the model. This user-supplied code has to be specifically written for specific applications of the model. It forms the basic part of the two simulation sub-models. It is often unique for the particular problem being solved. Full details of the components of the SIM-DY-SIM simulation model are discussed below.

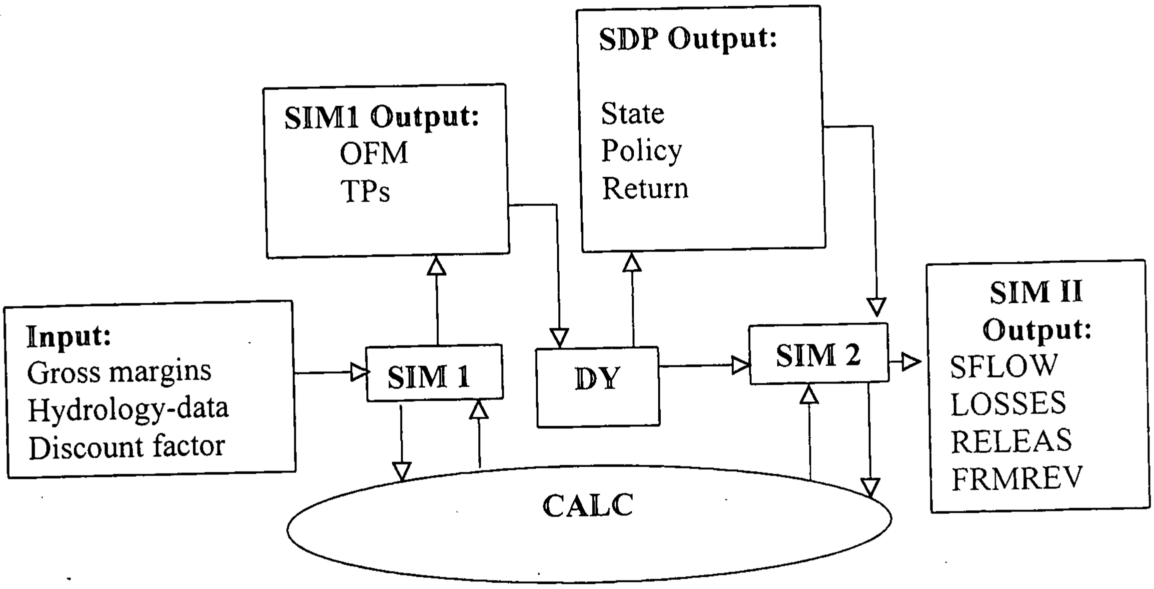


Figure 5.1: **The components and outputs of SIM-DY-SIM**

Source: Adapted from Dudley, 1999

Abbreviations:

OFM:	Objective function matrix
TPs:	Transition probabilities
SFLOW:	Streamflow
LOSSES:	Reservoir capacity share content losses
RELEAS:	Capacity share content releases made by farmer
FRMREV:	Farm revenue generated

5.3.1 Input data requirements

5.3.1.1 Gross margin functions

Running the model is initiated by inputting gross margins, which are derived from crop water gross margin functions. These GM are usually determined from LP solutions by changing the availability of water. The typical LP matrix that can be used to optimise gross margins at Vanderkloof Dam adopted from Mahlaha-Tsephe (2002) is shown in Table 5.1. The LP takes into consideration production activities and water consumed monthly, then optimises the gross margin realised under the constraints of monthly crop water requirements, tractor power and labour. With a given water quota and land, the programme also selects the maximum areas of each crop type to cultivate under all the above constraints.

Table 5.1: Linear programming matrix for determining optimal allocation of water at Vanderkloof Dam in the short-run, 2002

	PRODUCTION ACTIVITIES						WATER CONSUMED IN MONTHS (M^3/MONTH)														
	Wheatt	Maize	Lucernn	G. Nuts	Cotton	Potato	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May			
C	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	1	5.33	0	0.5	0.32													*0*	<=	x
February	0	0	5.33	0	0	0.64													*0*	<=	x
March	0	0	5.33	0	0	0.32													*0*	<=	x
April	0	0	5.33	8	0.32	16													*0*	<=	x
May	0	0	0	17.6	0	0													*0*	<=	x
June	2.73	1	0	0	0	0													*0*	<=	x
July	0.67	0.53	0	0.53	0.53	0.53													*0*	<=	x
August	0.32	0	0.8	0.53	0.53	1.67													*0*	<=	x
September	0	0	5.33	2.2	2.2	0.53													*0*	<=	x
October	0	0	5.33	1.21	1.12	2.67													*0*	<=	x
November	0	0	5.33	0	1	1.32													*0*	<=	x
December	0	3.94	5.33	2.66	1.32	0.32													*0*	<=	x
Labour (hrs/ha)																					
January	0	1	5.86	0	8	0.64													*0*	<=	x
February	0	0	5.86	0	8	1.28													*0*	<=	x
March	0	0	5.86	0	8	0.64													*0*	<=	x
April	0	0	5.86	96	0	230													*0*	<=	x
May	0	0	0	80	8	0													*0*	<=	x
June	2.73	0	0	0	0	0													*0*	<=	x
July	2.68	1.06	0	0.53	0.53	0.53													*0*	<=	x
August	0.64	0	1.6	0.53	0.53	1.67													*0*	<=	x
September	0	0	5.86	2.2	2.2	0.53													*0*	<=	x
October	0	0	5.86	4.2	3.84	26.7													*0*	<=	x
November	0	0	5.86	0	1	1.64													*0*	<=	x
December	0	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

Source: Adopted from Mahlaha, 2002

X = denotes maximum amount of a resource available

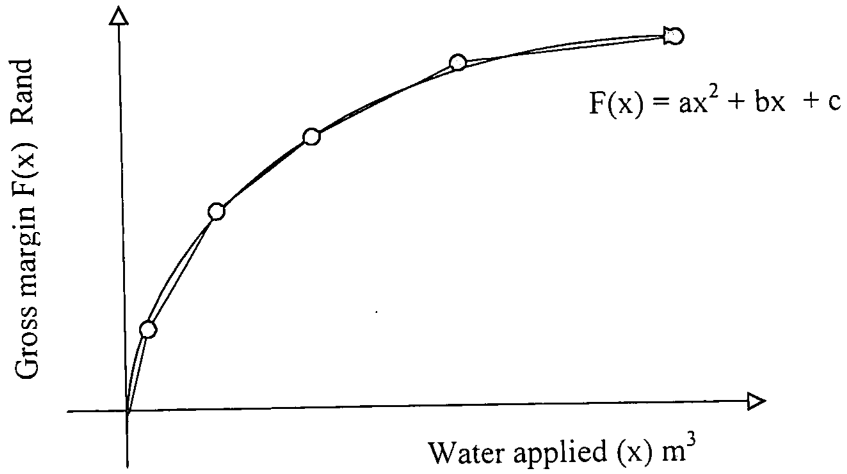


Figure 5.2: Typical gross margin function.

Generally, the gross margins derived from LP simulations are plotted to constitute gross margin function F(x) as in Figure 5.2. This function F(x), a fitted polynomial, or segmented linear equations represent seasonal gross margins expressed as function of reservoir water releases. However, the fitted second-degree polynomial may only be appropriate under certain conditions, e.g. when a variety of crops are produced in an area to fit a reasonably good polynomial-equation. These functions are vital for the determination of seasonal MVPs of water delivered to the farm.

5.3.1.2 Hydrology data

In addition to the gross margin functions, hydrology data for the river system used must also be available for the simulations. The hydrology data includes seasonal inflows into the storage facility or dam from which the user draws water, evaporation and seepage losses, and number of water releases made by sectors other than the sector being studied (e.g. Eskom). This information, when processed, will determine the quantity of water available to a sector (e.g. irrigation) for allocation as capacity shares. Any raw hydrology data obtained should therefore be processed to obtain seasonal inflows to the dam (system's storage space). Depending on the sectoral uses to which the dam contents are put, appropriate calculations must be made to determine the exact seasonal inflows that the specific sector (say the irrigation sector) is entitled to. This is essential as it forms the basis of allocation of shares to individual water users in that specific sector.

5.3.2 Pre-Dynamic Programming Simulation (SIM 1)

The purpose of this Pre-DP simulation sub model, Sim I, is to calculate expected gross margins and state variable transition probabilities for each combination of state and decision variable levels being considered. Sim I is similar to the second simulation (Sim II) in operation. The only difference is that the second simulation starts at decision point one in year one and proceeds sequentially through all years of data, employing the decisions selected as optimal by the SDP model for whatever system state evolves at the start of the next season, while the first divides the sequence into decision intervals and processes all the discrete combinations of state and decision variables for each interval.

Thus the first simulation model calculates a mean return for each state and decision variable combination at each decision interval of the season, as well as the state variable transition probabilities.

The expected return according to Dudley (1988), is represented as:............... $V_n(i,k)$

Where;

$V_n()$ is the mean gross margin in decision interval n given ( );

i is the i^{th} discrete combination of the state variables, at the start of stage when n stages remain; where i = 1,2..I

j is the j^{th} discrete combination of state variables at the end of stage when n stages remain; where j = 1,2..J

k is the k^{th} discrete level of the of the conditional decision variable, where k = 1,2..K

Dudley (1988), similarly represented the state variable transition probabilities derived by this simulation model as $P_n(i,j,k)$. This refers to the probability of the state variable combination changing from the i^{th} to the j^{th} combination during decision interval n when the conditional decision k is followed.

As a procedure, the first simulation sub model examines each decision interval as a separate entity before proceeding to others. With reference to Dudley and Hearn (1993), this procedure must be executed by setting i to the first discrete combination of state variables to be considered, and k to the first discrete level of the decision variable, at the start of the interval $n = 1$ for the first data year, before calculating the gross margin and change of state over the interval. This process is then repeated for the same interval in each of the remaining years of data, which provides information for $V_n(i,k)$ and $P_n(i,j,k)$ for $n,i,k, = 1$. After the repetition of the entire process for all combinations of i and k the programme proceeds to the next interval $n = 2$ and so forth until $n = N$, thereby forming N expected returns and N transitional probability matrices for input into the DP.

Starting with the optimal seasonal GM functions of reservoir releases plotted as Figure 5.2 together with seasonal inflows into a dam, Sim I will output for different farm groups:

- the objective function matrices for each season. These are n states by n decision variable matrices based on chosen p per cent intervals, where $n = (100/p) + 1$.
- transition probability matrices in the form i x j x k (since the reservoir content changes over time due to fluctuating seasonal inflows).

These outputs will serve as the input for the SDP.

5.3.3 Stochastic Dynamic Programming

The main purpose of the SDP is to select best water management strategies. These are optimal values of decision k for each state i in each decision interval, to satisfy the objective over the entire planning horizon. The targeted objective is to maximise expected gross margins over the planning horizon using the optimal quantity of water resources. On receipt of this information the SDP will therefore output:

- the state (i.e. quantity of water in the reservoir),
- policy decision variable (i.e. how much water to release),
- expected returns (signifying gains to the water user over the planning horizon if a specific policy is pursued), for each stage of the entire planning horizon. This is an important parameter from which the marginal value product (MVP) of water can

be determined. These MVPs determine what farmer can afford to pay for an additional unit of water.

Dudley and Hearn (1993) mentioned that an objective of this kind is stochastic and as such, the DP has to be programmed to process the intervals in the reverse order to real time, by backward recursion. That implies reversing the order of intervals as stages, so that Stage 1, for example, refers to the last interval in the planning horizon. According to Dudley and Hearn (1993), the DP should begin its run in Stage 1 by calculating:

$$f_1(i) = (\max V_1(i, k) \;+\; B_1P_1(i, j, k)f_0(j)) \ldots\ldots\ldots\ldots\ldots \text{(Eq. 5.2)}$$

this would mean choosing k (from the feasible set, K) to maximise the mean return over Stage 1. Next, the DP calculates:

$$f_2(i) \;=\; \max (V_2(i,k) \;+\; B_2P_2(i, j, k)f_1(j)) \;\ldots\ldots\ldots\ldots\ldots \text{(Eq 5.3)}$$

where B_2 is the discounting factor for Stage 2 and $f_2(i)$ is the maximum present value of expected return over the last two stages of the planning horizon.

The recurrence relation which effectively calculates recursively the optimal (i.e. maximum) present value of expected remaining returns for each stage, at Stage n given the optimal remaining returns for each state of stage $n-1$ is given by equation 5.1.

It is essential to note that only strategies from the very last year of the DP planning horizon are used in the second simulation sub-model. This is because the second simulation sub-model must use converged policies when simulating the operation of the system over an infinite planning horizon. The optimal convergent policy (OCP) is therefore of prime importance. This OCP will serve as the input for the second simulation (Sim II).

5.3.4 Post-Dynamic Programming (SIM II)

Following Dudley and Scott (1993) and Dudley and Hearn (1993), the purpose of this second simulation sub-model is to simulate the effects of using the optimal decisions derived by the SDP. These decisions are the optimal discrete water releases from a farmer's capacity share. This sub-model at each decision point as it proceeds sequentially through the available years of historical inflow data, reads the water use data for each decision interval from the output of the LP. It then calculates the changes in the farmer's capacity levels across decision intervals by adding inflows and subtracting spills, reservoir evaporation losses, and releases required to satisfy farm optimal use. Also at the end of each season and year, the programme outputs the seasonal revenue as well as the net annual revenue. At the start of each new season, SIM II reads in the inflows for the season as stipulated by the hydrology data. The capacity share content at the start of the season determines the volume of water that must be released based on the optimal reservoir release decision according to the SDP. Thus the programme makes a check at the start of each season to ensure that the reservoir level is sufficient to justify any current releases for the season. If the reservoir level is low in a season due to the stochastic inflows, water releases are reduced proportionately.

That means as SIM II goes through the decision intervals of the hydrology data, there will be decision points at which the DP results will indicate the reduction of water releases given current state variable levels (i.e. reservoir content). This implies that the optimal decisions from the DP, which are in terms of water releases in the immediate decision interval, are actually maximum releases instead of actual releases. Therefore SIM II will not permit releases exceeding that recommended by the DP and will actually release less in the event of insufficient water levels.

Sim II shows water users the simulated results from two very different policies. The first employs the optimal water saving decisions derived by the SDP model. The second uses water as it becomes available in the user's storage capacity share with no thought of saving water for future periods. Both outputs provide relevant statistical information about stream-flow, seasonal as well as annual farm revenue, and farmers' mean inflows. This valuable statistical information can be compared to determine the consequences of following optimal water saving plans against no planning ahead.

After the initial run of the SIM-DY-SIM model, capacity shares (CS) as well as inflow shares (IS) may be changed to simulate different states of water availability. This means the reservoir capacity shares or inflow shares have to be reduced (to simulate shortages) or increased (to simulate extra water) by different percentages to indicate costs or gains of the resulting water shortages (excess) to the farm and the corresponding best management responses.

A base case (BC) must first be chosen, which normally means 100 per cent of CS and inflow shares (IS). In a base case, the size of the farmer's reservoir capacity share (CS) will be chosen so that the maximum contents of the capacity share is just sufficient to maximise the farm gross margin in the season of the highest demand. Reservoir evaporation and seepage losses and dam-to-farm transmission losses are not considered when determining this capacity share size. The size of the inflow shares (IS) for the base case (BC) will also be chosen so that the mean seasonal inflow share is equal to the quantity of water required to maximise the farm gross margin, again with no losses taken into account.

5.4 SUMMARY

Under the appropriate institutional arrangement the adopted SIM–DY–SIM model has the potential to allocate irrigation water resources optimally. It takes into account non-uniform hydrological conditions; restrictions between supply and demand; maximum and minimum resource availability and storage capacity of reservoirs assumed to be controlled by water users.

The LP provides useful information on water allocation on the farm by the farmer and also provides the gross margins that farmers receive. This information is crucial for the SDP simulations. In addition, the LP supplies information regarding the finding of short-term marginal values of water.

In the SIM–DY–SIM model, the optimisation process is extended to 19 years using simulated data to capture fluctuations in hydrological conditions so as to determine or forecast with a high degree of certainty water users' supply reliability. Forecasts made using results from the model will therefore aid decision-making regarding consuming water at the present time or saving it for the future.

The mean returns calculated for each state and decision variable combination at each decision interval will provide the farmer with valuable information regarding optimal water-use decisions. Transition probabilities, though not displayed for farmers' perusal, form an integral part of other simulations to determine water supply reliability.

Selecting the best water management strategies under a stochastic environment is made easier by the SDP simulation. With optimal values regarding:

- the quantity of water in the reservoir;
- how much water to release; and
- expected returns for each stage of the entire planning horizon,

calculated over an entire planning horizon, the objectives of maximising expected gross margins using optimal quantities of water resources will be realised.

Simulating the effects of using optimal decisions derived by SDP, provides a tool for forecasting future water management over an extensive period pertaining to:

- reservoir inflows;
- farmers reservoir levels, (that are linked to inflows, releases; spills and evaporation); and
- optimal water releases required to satisfy farm optimal use,

which are vital for sustainable water management over time.

The SIM–DY–SIM model is thus versatile in the sense that it can be used to derive the MVPs of both reservoir water and reservoir storage space for irrigation farmers at various water scarcities of both water and storage space. Hence the true economic value of reservoir contents and reservoir capacity for different, individual capacity holders in this water use sector can be determined. In addition the model indicates optimal returns that will accrue to water users at different water application levels, a tool that is vital for the water user's decision making.

5.5 CONCLUSION

The evaluation of institutional arrangements recommended Capacity Sharing as an alternative institutional framework for managing South Africa's water resources in a sustainable manner. Because integrated demand and supply management is one of the main features of capacity sharing, its selection is warranted. A new methodology for its implementation therefore has to be developed before it can be adopted for use.

The computer model SIM–DY–SIM discussed above provided the methodology for achieving the desired goal of integrated demand and supply. It is imperative to test the appropriateness of this methodology in order to validate its use.

To test the applicability of this SIM–DY–SIM model Vanderkloof Dam was targeted for a case study. The next chapter gives full account of the case study.

CHAPTER 6

OPTIMAL WATER MANAGEMENT STRATEGIES FOR IRRIGATION WATER USERS AT VANDERKLOOF DAM.

6.1 INTRODUCTION

Vanderkloof Dam was selected for a case study to test the application of the SIM-DY-SIM model, which was adopted from Australia. The study involves the farming community who is served by the Ramah Canal. A questionnaire was developed and survey conducted on three identified farmer groups. Survey results were used to run a linear programming (LP) model, which was developed to output gross margins that the farmers can receive at different water application levels. The relevant survey and LP results, together with hydrology data, which form direct inputs into the SIM-DY-SIM model, will be presented in this chapter. Empirical results of the model will then be discussed, by looking at the raw outputs that emerge from the data processing.

6.2 DATA ACQUISITION

6.2.1 Survey

Before the survey a questionnaire was developed and tested at the study area, farmers were then classified according to groups. The classification was conducted on the basis of irrigated water rights that farmers can possess. Three farmer groups were identified. These are farmers with irrigated water rights less than 100 ha, or between 100 to 200 ha and those above 200 ha.

Centre-pivot irrigation system is used virtually by all farmers in the area. With one centre-pivot irrigating 60 ha, farmers with less than 100 ha of water rights have 60 ha under the pivot and 15 hectares under sprinklers. A seventy-five hectare plot is thus taken as a good representation of area cultivated by this group of farmers (small farm size group). The farmers at Vanderkloof Dam are predominantly maize and wheat farmers. Crops like lucern, potatoes, cotton and groundnuts are cultivated only on a small-scale comparatively. Farmers prefer cultivating small-scaled crops in multiples of 15 ha.

For modelling purposes, a farm size of 180ha was selected for farmers between 100 and 200 ha farms. Farmers in the 100 to 200 ha group, use two centre-pivots and sprinklers for crops that are on small scale. On average, two types of crops are selected from the small-scale crops. The practise of the third group (i.e. the large farm size group which is above 200 ha) is the same as for the medium size group, except that more pivots are in use. A 240 ha farm is taken as the best representation of the largest farm group.

Crop budgets were also compiled in conjunction with the Free State Department of Agriculture and confirmed with farmers in the study area during the survey. These budgets show the gross margins that the farmers obtained when a crop is cultivated and were used as an input to the LP.

During the survey, farmers' financial records were also collected and processed to compile their liabilities and net worth, which are needed for determining farmers' discount rates. The discussion of the survey results is not part of this thesis. For detailed discussion see Mahlaha, 2002.

6.2.2 Linear Programming (LP)

The LP matrix in Table 5.1 takes into consideration production activities and water consumed monthly, then optimises the gross margin realised under the constraints of monthly crop water requirements, tractor power and labour. With a given water quota and land, the programme also selects the maximum areas of each crop type to cultivate (see Mahlaha, 2002).

An LP-model was developed separately for both summer and winter farming activities for the three farm sizes identified to generate the optimal seasonal gross margins in each case. In this thesis two of the above cases namely 75 ha farmer producing maize lucern and wheat (referred to as Summer Crop Mix 1/Wheat) or potato, maize and wheat (referred to as Summer Crop Mix 2/Wheat) were identified for analysis. Mainly due to the comprehensiveness of data, it was decided to use summer crop mixes 1 and 2 only with wheat as winter crop for a 75 ha farm in this thesis.

Results from the LP model for a 75 ha farmer for both cases (Summer Crop Mixes 1 and 2 and Wheat as winter crop) are presented in the Tables 6.1, 6.2 and 6.3. In Table 6.1maize and lucern are produced with a maximum of 15 ha of lucern production. As shown in Tables 6.1 and 6.3, maize and lucern are summer crops while wheat is the only winter crop. Despite the fact that lucern is an annual crop, it is been accommodated as a summer crop, mainly because the SDP model considers gross margins on seasonal basis. Lucern is only active and harvested in summer, hence it is more convenient for the model specifications to take this crop as a summer crop.

According to the LP results (Table 6.1) for Summer Crop Mix 1, a farmer can only produce a maximum of 15 ha of lucern with a gross margin of R 40 800 if he has 225 000 m^3 of water available. The LP model selected lucern first due to its higher gross margin regardless of its production being more water intensive. Maize production can only start if farmer has beyond 250 000 m^3 of water available. For Summer Crop Mix 1, the maximum gross margin realised was R 86 280 when 727 200 m^3 of water is used with 60 ha of maize and 15 ha of lucern planted.

Summer Crop Mix 2 represents a 75 ha farm situation where a farmer plants potatoes (maximum of 15 ha) and maize in summer and wheat in winter as indicated in Tables 6.2 and 6.3. A farmer in Summer Crop Mix 2 will produce only potatoes if his water supply is 66 750 m^3 and less with a gross margin of R 243 225. Maize production can only start when available water is above 80 000 m^3. A total gross margin of R 288 705 could be realised in this case with a maximum of 568 950 m^3 of water consumed if the entire 75 ha farm is utilised with 15 hectares for potatoes and 60 ha for maize. The winter crop wheat used much less water of 357 600 m^3 for 60 ha.

In summary a farmer operating under Summer Crop Mix 1/Wheat shown in Tables 6.1 and 6.2 would need a total of 1 084 800 m^3 (i.e. 727 200 + 357 600 m^3) of water for his annual production to generate a gross margin of R 224 760 (i.e. R86 280 + R138 480). Summer Crop Mix 2/Wheat farmer on the other hand, as shown in Tables 6.2 and 6.3, would consume much less water, that is 926 550 m^3, (i.e. 568 950 + 357 600 m^3) and generate a gross margin of R 427 185 (R288 705 + R138 480) which is almost double that under Summer Crop Mix 1/Wheat.

Table 6.1: Optimal crop areas and resulting gross margins for a 75 ha farm at different water applications at Vanderkloof Dam; - Summer Crop Mix 1, 2000

Water applied (m^3)	Area selected (Ha)		Gross Margin (R)
	Maize	Lucerne	
0			0
50 000		3.3	9 067
100 000		6.7	18 133
150 000		10	27 200
200 000		13.3	36 267
225 000		15	40 800
250 000	3	15	43 064
300 000	9	15	47 592
400 000	21	15	56 648
500 000	33	15	65 704
600 000	45	15	74 761
700 000	57	15	83 817
727 200	60	15	86 280

Table 6.2: **Optimal crop areas and resulting gross margins for a 75 ha farm at different water applications at Vanderkloof Dam; - Summer Crop Mix2, 2000**

Water applied (m^3)	Area selected (Ha)		Gross Margin (R)
	Maize	Potatoes	
0			0
20 000		4.5	72 876
40 000		9	145 753
60 000		13.5	218 629
66 750		15	243 225
80 000	1.6	15	244 425
100 000	4	15	246 236
200 000	16	15	255 292
300 000	28	15	264 349
400 000	40	15	273 405
500 000	52	15	282 461
568 950	60	15	288 705

Table 6.3: **Optimal crop areas and resulting gross margins for a 75 ha farm at different water applications at Vanderkloof Dam; – Winter crop (Wheat), 2000**

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

The gross margins of the crop mixes in Tables 6.1, 6.2 and 6.3 were plotted against water applied and these constitute the segmented linear equations for a 75 ha farmer for the crop mixes mentioned above. These are presented in Figures 6.1, 6.2 and 6.3. In these figures, water consumption and gross margin generated are linearly related in all cases. It is evident and conclusive from Figures 6.1 and 6.2 which represent the two crop mixes discussed above that, crops with higher gross margins per unit of water applied were first selected by the LP-model.

The first derivative of these linear equations also represents the MVP for water delivered to the farm for use in the current season. This MVP will be discussed into details later in the chapter. The segmented linear equations are major inputs into the SIM-DY-SIM model. Farm sizes 180 and 240 are not discussed in this thesis but summaries of their LP results are given in Tables A1 to A6 in Appendix A and Figures B1 to B6 in Appendix B. Discussion of these results will be found in the WRC report of which this thesis only forms part.

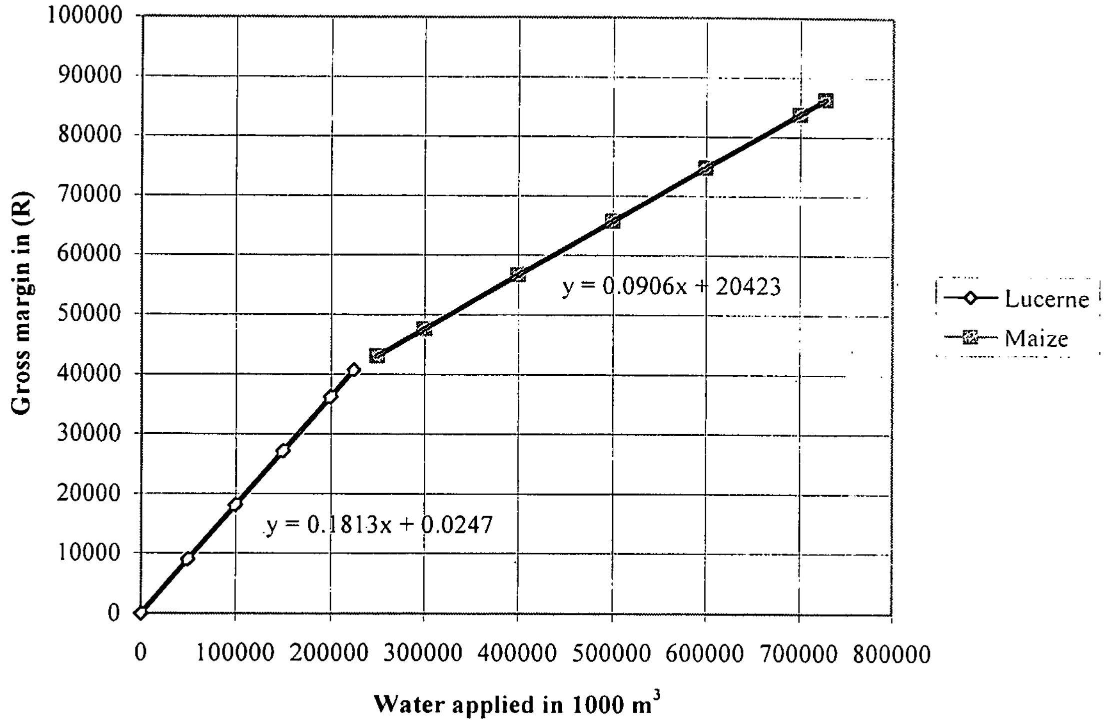


Figure 6.1: **Gross margin as a function of water applied for 75 ha farm; Summer Crop Mix 1, 2000**

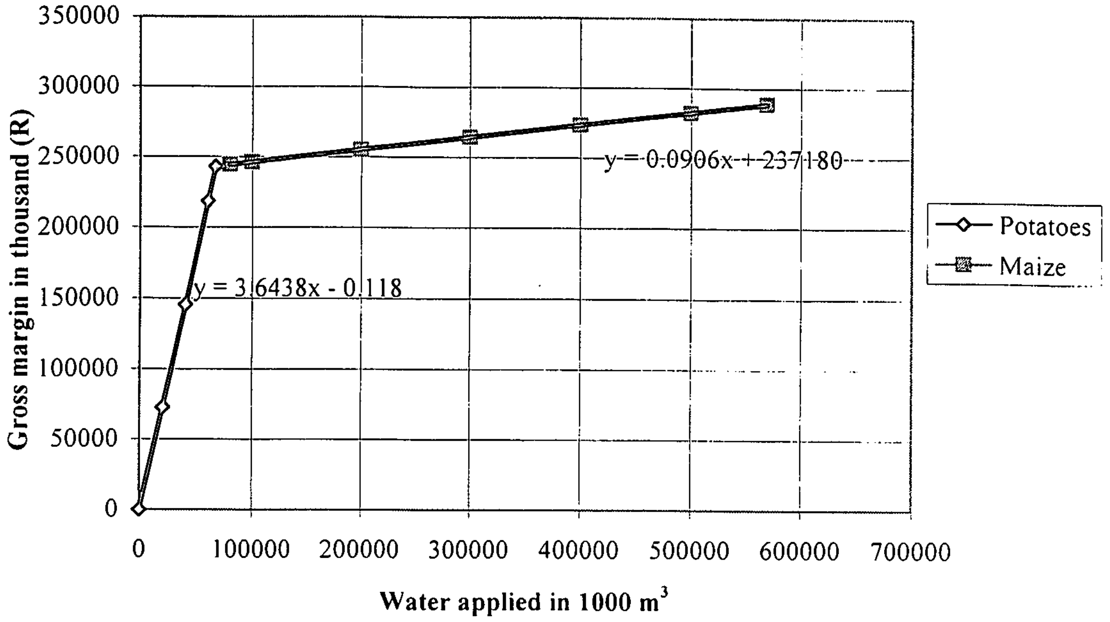


Figure 6.2: Gross margin as a function of water applied for 75 ha farm; Summer Crop Mix 2, 2000

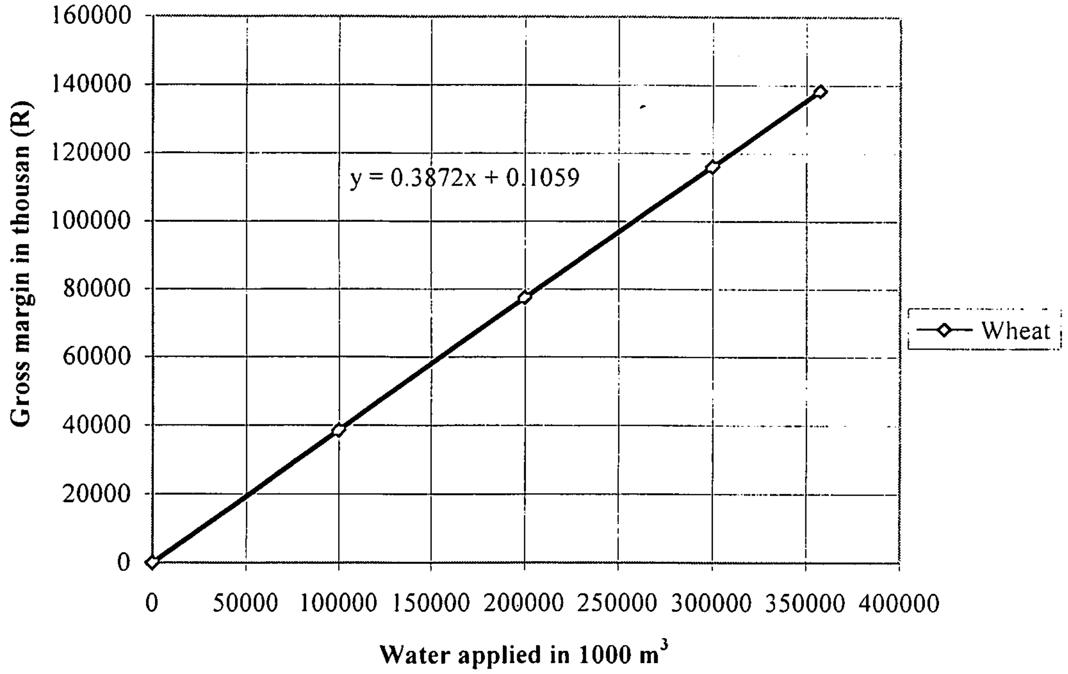


Figure 6.3: Gross margin as a function of water applied for 75 ha farm; Winter crop, 2000

6.2.3 Hydrology Data

The next input into the SIM-DY-SIM model is the inflows into the reservoir storage of Vanderkloof Dam. Two different hydrology data were considered in this work. These are:

- Nineteen years inflow data for Vanderkloof Dam recorded by Department of Water Affairs and Forestry.
- Simulated hydrology data obtained from WRP consulting engineers.

The simulated data was based on joint Vanderkloof and Gariep Dam operating procedure, which is carried out primarily to balance the two dams.

Table 6.4: Seasonal inflows (10^6 m^3) into Vanderkloof Dam for the period 1977-1995

Year	Winter inflows 1 April– 31 Aug	Summer inflows 1 Sept – 31 March
1977	2231.84	7648.60
1978	3296.69	3294.07
1979	864.38	4171.36
1980	1277.05	2405.07
1981	2190.50	2272.23
1982	708.82	3085.62
1983	360.70	1735.53
1984	728.18	1744.41
1985	635.77	1647.41
1986	1094.55	3461.39
1987	881.05	2784.08
1988	3701.62	12669.35
1989	3626.05	7742.97
1990	2290.30	2144.29
1991	1962.71	3660.53
1992	986.13	2710.46
1993	543.55	1490.62
1994	1210.96	3461.83
1995	230.53	1343.57

Source: Derived from Department of Water Affairs and Forestry, 2000

That is, high water releases are made at Vanderkloof Dam during winter (to cater for the high electric power demand), consequently creating space for summer inflows (releases) from Gariep. This procedure gave rise to some negative seasonal inflows that are unacceptable for CS modelling. The 19 years inflow data recorded by DWAF was therefore used in running the model.

* The suitability of using this data is discussed in the WRC report of which this thesis only forms part.

Table 6.4 shows the inflows into Vanderkloof Dam as recorded by DWAF since the inception of the dam in 1976. As reflected in Figure 6.4, which is derived from Table 6.4, (seasonal inflows from 1977 to 1995) depict an irregular inflow pattern with higher inflows on the average registered in summer

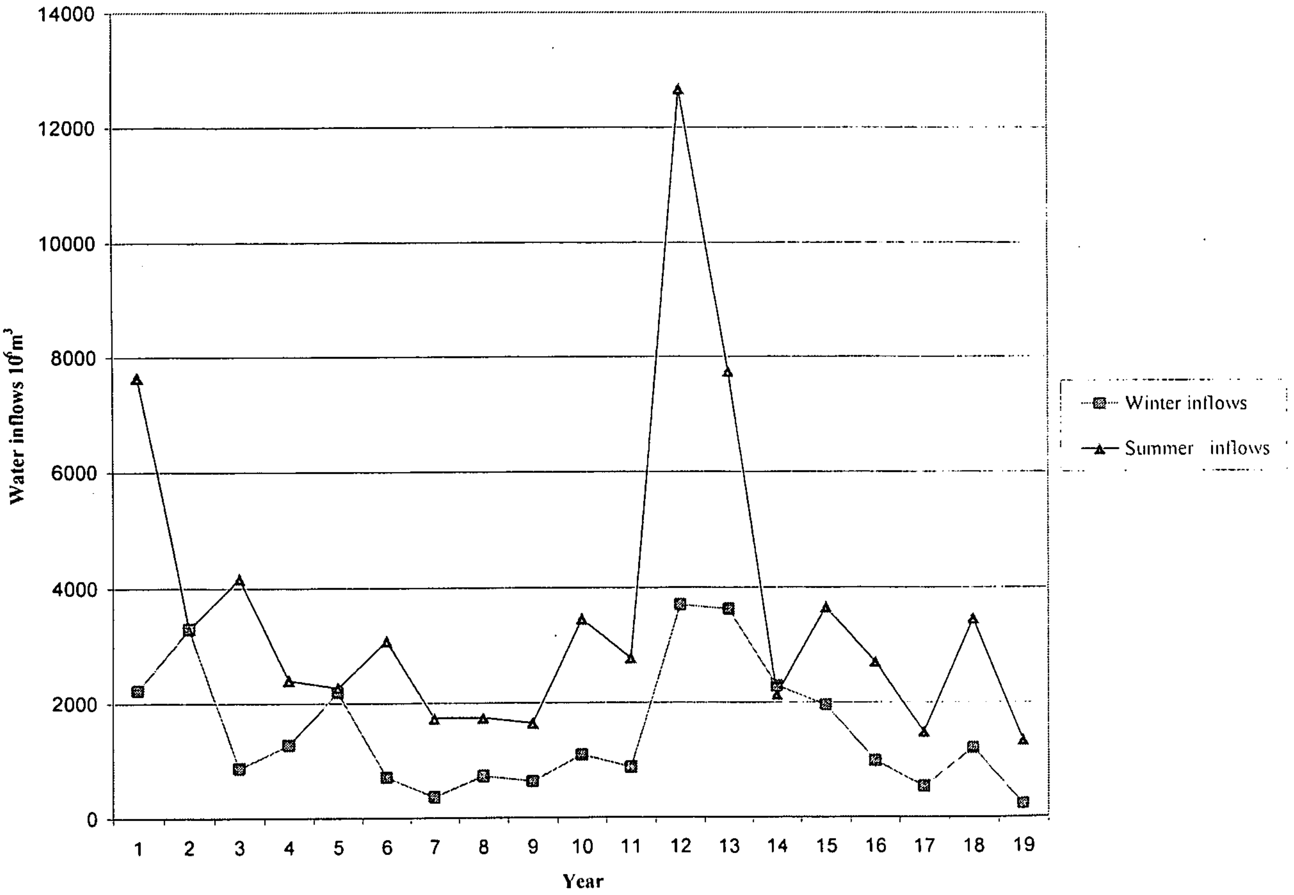


Figure 6.4: Seasonal inflows into Vanderkloof Dam for the period 1977 to 1995.

Source: Derived from Department of Water Affairs and Forestry, 2000

6.2.4 Discount Rate

Discounting plays a vital role in through-time (i.e. dynamic) decision-making as it reflects the weighting of future income on current decisions. Thus, in order to facilitate comparison of results when time is important, discounting must be conducted with suitable discount factors. After conducting a literature study it was decided to use the weighted average cost of capital (WACC) as the discount factor at farm level. The summary of discount rates for farmers used in this study are found in Table 6.5. Unlike in Meiring and Oosthuizen (1991), where farmer categories in the determination of discount rates were based on selected percentages of equity proportions, in this research, it is based on farm sizes of 75, 180 and 240 ha. Using the October, 2001 interest rates supplied by Amalgamated Bank of South Africa (ABSA), assuming a 10 per cent return on own capital and 25 per cent marginal tax rate, the discount rates were found to be 10,2; 10,7 and 10,2 per cent respectively for a 75, 180 and 240 ha farmer (Table 6.5). A flat discount rate of 10 per cent is therefore chosen for running this model.

Table 6.5: Discount rate for Vanderkloof Dam farmers in 2001

Liabilities	**FarmType**		
	75ha farm	**180ha farm**	**240ha farm**
Short-term liabilities(R)	482 540	611 250	1 351 122
Medium-term liabilities (R)	109 602	669 333	711 800
Long-term liabilities (R)	353 232	1 095 515	315 590
Total liabilities (R)	945 374	2 376 098	2 378 512
Net worth (R)	2 706 932	4 970 364	10 010 019
Total Capital (R)	3 060 164	6 065 879	10 325 609
Weighted Average Cost of Capital (WACC) %	13.40	14.20	13.43
WACC after tax (%)	**10.20**	**10.70**	**10.20**

6.3 EMPIRICAL RESULTS

The empirical results include marginal value product (MVPs) of water obtained from the LP-results for input into the SIM-DY-SIM model to aid inter-season decision-making.

Very briefly outputs from the SIM-DY-SIM model are Sim I outputs; SDP outputs; and Sim II outputs. Before the results are discussed it is very important to note that in this study four distinguished MVPs and three different markets are identified. The MVPs include;

- LP-derived MVPs, (these have no direct significance regarding capacity sharing) are used to indicate the value of water delivered onto a farm for use in the immediate season,
- The SDP derived MVP, which is the marginal value product of water in the reservoir. This is used for inter-season decision making.
- The MVP for long term inflow shares and,
- The MVP for long term capacity shares or empty space in the reservoir.

The last three MVPs are all dependent on the LP derived MVPs.

The three markets mentioned earlier include;

- Market for water already in the reservoir,
- Market for capacity shares and,
- Market for inflow shares.

The third and fourth MVPs mentioned above as well as markets for long term capacity shares and inflow shares are beyond the scope of this thesis, hence only the first-two MVPs and market for water already in the reservoir will be discussed.

6.3.1 MVPs DERIVED FROM LP FOR INPUT INTO INTER-SEASON DECISIONS

Table 6.6 summarises the ability of a 75 ha farmer to pay for water when production is limited to specific crops as a result of water scarcity or availability. According to the LP results, the farmer's ability to pay for summer water ranges between R 0,09 and R 0,18 per m^3 when lucern and maize are cultivated as summer crops and between R 0,09 and R 3,64 per m^3 when potato and maize are cultivated. These values are MVPs for water delivered onto the farm for use in the current season. Further explanation of these MVPs is given below.

Table 6.6 **Marginal Value Products (MVPs) of water for a 75 ha farmer on Ramah Canal, at Vanderkloof Dam, 2000**

CROP MIX	SEASONAL CROPS' MVPs		
	SUMMER		WINTER
1	**Lucern**	**Maize**	**Wheat**
	R 0,18 /m^3	R 0,09 /m^3	R 0,39 /m^3
2	**Potatoes**	**Maize**	**Wheat**
	R 3,64 /m^3	R 0,09 /m^3	R 0,39 /m^3

Figures 6.5 and 6.6 show the MVPs for the two seasons (winter/summer) derived from the segmented linear functions in Figure 6.1 through 6.3. These MVP functions conform to the stepwise demand functions normally obtained from LP solutions (Hazel and Norton, 1986). The MVPs differ significantly for the two seasons since the seasonal production activities as well as water availability vary.

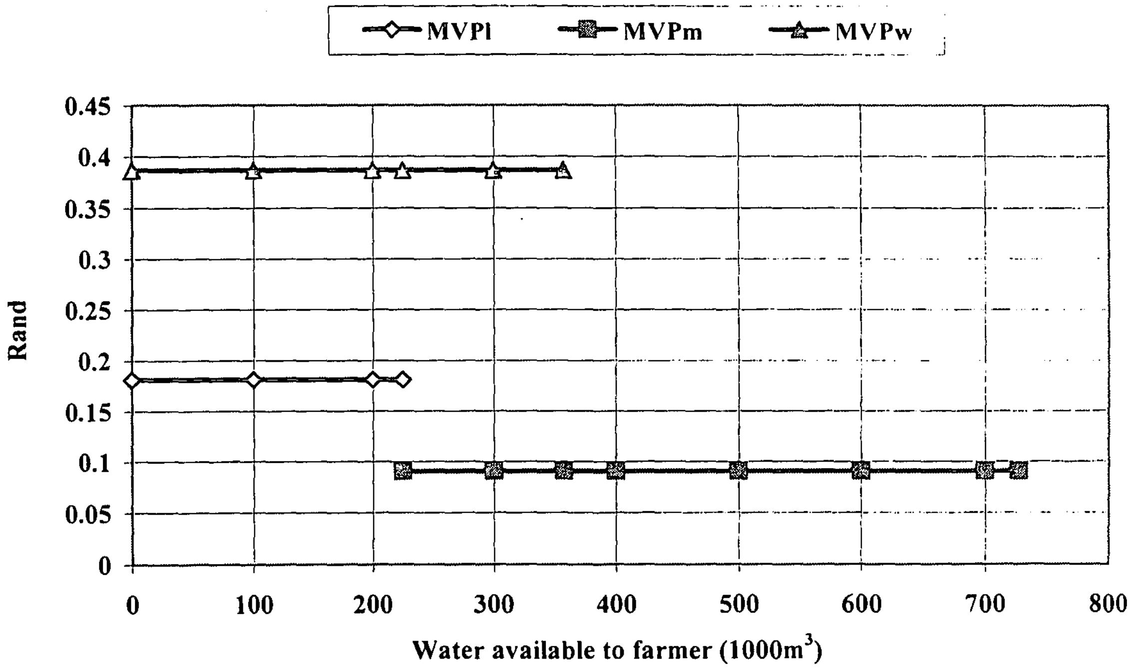


Figure 6.5: **Water MVPs (R/m^3) resulting from LP simulation for a 75 ha farmer on Ramah Canal at Vanderkloof Dam; Summer Crop Mix 1/Wheat (LMW), 2000.**

For immediate use during the summer season, a 75 ha farmer cultivating maize and lucern can afford to pay R 0,18 per m^3 for the first 225 000 m^3 of water. As water becomes more abundant say between 225 000 and 727 200 m^3 however, the farmer can afford to pay about half that amount which is R 0,09. In winter, on the other hand, where farmer is engaged fully on wheat production, he can afford to pay a much higher tariff, which is R 0,39 per m^3 so long as the water available to him is less than 357 600 m^3. (MVPl, MVPm and MVPw in the legend stand for marginal value products of water for lucern, maize and wheat respectively). It is important to note that all these MVPs are based on the year 2001 prices for inputs and outputs

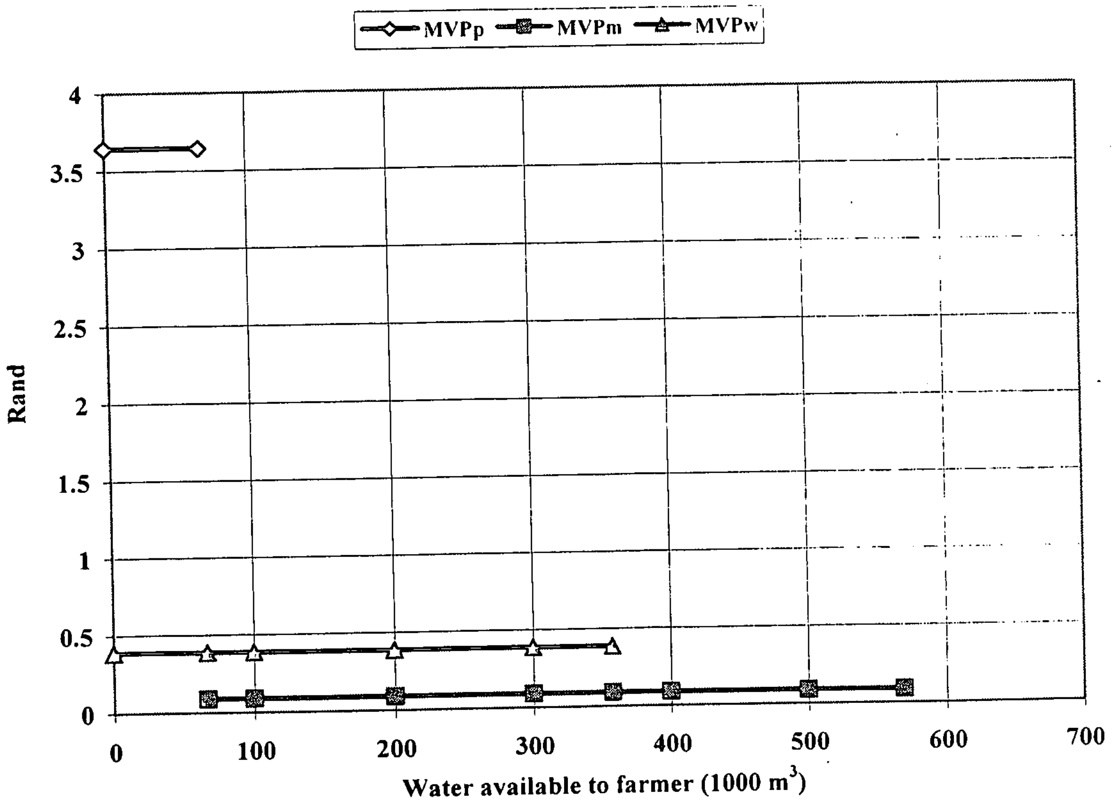


Figure 6.6: **Water MVPs (R/m^3) resulting from LP simulation for a 75 ha farmer on Ramah Canal at Vanderkloof Dam; Summer Crop Mix 2/Wheat (PMW), 2000.**

Under a different scenario of a 75 ha farmer, cultivating potatoes and maize in summer followed by wheat in winter (Summer Crop Mix 2/Wheat), the farmer will be able to pay as high as R 3,64 per m^3 for water delivered onto the farm for immediate use if the water available is less than 66 700 m³. However, beyond 66 700 m³ with a ceiling of 568 950 m³ farmer can only afford about R 0,09 per m^3 of water. For winter production the farmer can afford the same amount, R 0,39 per m^3 as in Summer Crop Mix 1/Wheat since the winter production in both cases remain the same and again, the assumption of 2000 prices remain. (MVPp, MVPm and MVPw in the legend stand for marginal value products of water for potato, maize and wheat respectively).

6.3.2 SIM-DY-SIM OUTPUTS

The state and decision variables as well as constants-per-stage referred to as CX values, which may provide some background information in this analysis are also outputted, see Table 6.7 below.

S1, S2 and S3 are the state variables. The model makes provision for three state variables but in this study only one is used. The only state variable here, which is the quantity of water in the reservoir, is represented by S3. This variable takes a minimum value of 1 (empty reservoir), increasing at two percentage points per state to 51 states, where the state 51 represents 100 per cent reservoir capacity. S1 and S2, which are not used, are therefore assigned the value 1 meaning they are inactive in the model.

Table 6.7: State and Decision variables with constants-per-stage values.

S1MIN = 0.00	S1INC = 1.00	S1INT = 1.00
S2MIN = 0.00	S2INC = 1.00	S2INT = 1.00
S3MIN = 0.00	S3INC = 2.00	S3INT = 51.00

D1 and D2 refer to decision variables and in this study only one decision variable is present, that is quantity of water to release. D1 represents this decision variable and also assumes a minimum value of 1 (no releases) with increments of 2 units having in all 51 decisions, where decision 51 implies 100 per cent releases.

D1MIN = .00	D1INC = 2.00	D1INT = 51.00
D2MIN = .00	D2INC = 1.00	D2INT = 1.00

The explanations of the 12 CX values where X = 1, 2...,12 as well as their definitions are as follows;

C1 = is the percentage of the seasonal release from the farm's reservoir capacity share that reaches the farm. This implies releases less transmission losses from the dam to the farm are 90 per cent (a 10 per cent transmission and seepage losses are assumed).

C2 = is a redundant parameter and not applicable to this study hence set to zero.

C3 = initialises the value of the capacity share contents in the first of the seasons (e.g. 19 x 2 in the Vanderkloof Dam case) simulated in Sim 2. CS content is taken to be 100 per cent from the start.

C4 = minimum percentage value of capacity share contents in the simulations. The barest minimum of CS contents is zero.

C5 = maximum percentage value of capacity share contents in the simulations. The maximum allowable CS content is 100 per cent in this case.

C6 = size of the farm's reservoir capacity share as a proportion of the base case when that proportion is 1 or less.

C7 = size of the farm's reservoir inflow share as a proportion of the base case when that proportion is 1 or less.

C8 = size of the farm's reservoir capacity share as a proportion of the base case when that proportion is 1 or more.

C9 = size of the farm's reservoir inflow share as a proportion of the base case when that proportion is 1 or more.

C10 = a factor to convert the whole-dam inflow into the farm's reservoir capacity share inflow. This factor is 0.0001989. This means approximately 2 per 10 000 of reservoir inflow is assigned to a CS share.

C11 = maximum quantity of water in thousands of m^3 that the season with the higher water demand (in this case summer), can profitably use. This is 727 200 m^3 as deduced from the LP output.

C12 = redundant as in C2 above.

C1 = .90	C2 = 0	C3 = 100
C4 = 0.00	C5 = 100.00	C6 = 1.00
C7 = 1.00	C8 = 1.00	C9 = 1.00
C10 = 0.00	C11 = 727.20	C12 = 0.00

6.3.2.1 Sim 1 Outputs

The main outputs from Sim 1 are a pair of summer and winter objective function matrices, which are 51 states (the farmer's reservoir contents) by 51 decision (water releases) interval matrices. These are given in Tables A7 and A8 in Appendix A In these tables the decision taken at any state of the resource and the corresponding gross margin (GM) generated are summarised. An extract from Table A7 is given below for the sake of explanation. The column S3 shows the state of the resource (i.e. 51 states of 2% intervals). Water release decisions (also 51 decisions of 2% intervals) are arranged horizontally. Given State 6, for example under S3, and following decision 6 gives the gross margin of R11 870. That is, Sim 1 calculates the GMs for each of the 51 alternative decisions for each of the 51 states for this stage.

Table 6.8: **Part of the summer objective function matrix produced by Sim 1 for base case (lucern, maize and wheat) for farmers on Ramah Canal, 2001.**

	DECISION								
	1	2	3	4	5	6	7	8	9
State (S3)									
1	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
3	.00	2.37	4.75	4.75	4.75	4.75	4.75	4.75	4.75
4	.00	2.37	4.75	7.12	7.12	7.12	7.12	7.12	7.12
5	.00	2.37	4.75	7.12	9.49	9.49	9.49	9.49	9.49
6	.00	2.37	4.75	7.12	9.49	11.87	11.87	11.87	11.87
7	.00	2.37	4.75	7.12	9.49	11.87	14.24	14.24	14.24
8	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	16.61
9	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
10	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
11	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
12	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
13	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
14	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
15	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99

The transition probability matrices have not been printed mainly because of their hugeness. For each of the 51 starting states there are 51 possible ending states for each of the 51 decisions, resulting in a 51 X (51 X 51) matrix.

6.3.2.2 SDP Output

The optimal policies, and the resulting present value of expected optimal remaining returns (gross margins) for each state at various stages of the farmer's planning horizon are part of the output of the SDP sub-model. For the sake of explanation, a typical SDP output for Stage 13 is presented in Tables 6.9a. Stage 13 refers to the thirteenth season to the end of the farmer's planning horizon. It is worth noting that, at the end of the farmer's planning horizon any water left in storage is assumed to have zero value to the farmer. In this study 6.5 to 7 years was chosen because the model output showed that cessation of irrigation farming at the end of that time appeared to have zero impact on current decisions across the various runs or solutions of the SDP model. Table 6.9a specifies three items, namely; the state, the policy (decision) and the returns.

The state in applications of the SDP model in this study refers to the quantity of water in the farmer's share of capacity of the Vanderkloof Dam (CS contents). Table 6.9a shows 51 state levels at intervals of 2 per cent. Therefore, in this case, the CS content as a percentage of capacity share is given by the formular (State – 1) x 2. * State 1 for example in Table 6.9a refers to zero CS content whiles a state of 26 implies a CS content of 50 per cent, of the 727 200 m^3 capacity share.

Table 6.9a: States, policies and present values of expected optimal remaining returns in stage 13 for (base case) 75 ha lucern, maize and wheat for farmers on Ramah Canal at Vanderkloof Dam, 2001.

STATE	POLICY	RETURN	STATE	POLICY	RETURN	STATE	POLICY	RETURN
0 1	1	.81063330E+03	18	18	.85010630E+03	35	28	.87193900E+03
0 2	2	.81300650E+03	19	18	.85190280E+03	36	29	.87312490E+03
0 3	3	.81530150E+03	20	19	.85324230E+03	37	30	.87431080E+03
0 4	4	.81767470E+03	21	18	.85483400E+03	38	31	.87549670E+03
0 5	5	.82004780E+03	22	18	.85650810E+03	39	32	.87668270E+03
0 6	6	.82242090E+03	23	19	.85792600E+03	40	33	.87786860E+03
0 7	7	.82479410E+03	24	22	.85882110E+03	41	34	.87905450E+03
0 8	8	.82716720E+03	25	19	.86008150E+03	42	35	.88024040E+03
0 9	9	.82949150E+03	26	19	.86129930E+03	43	36	.88142630E+03
0 10	10	.83186460E+03	27	20	.86248520E+03	44	37	.88261220E+03
0 11	11	.83423780E+03	28	21	.86367120E+03	45	39	.88372190E+03
0 12	12	.83661080E+03	29	22	.86485710E+03	46	39	.88473600E+03
0 13	13	.83898410E+03	30	23	.86604300E+03	47	41	.88580020E+03
0 14	14	.84106160E+03	31	24	.86722890E+03	48	42	.88674160E+03
0 15	15	.84343480E+03	32	25	.86841480E+03	49	42	.88780470E+03
0 16	16	.84560450E+03	33	26	.86960070E+03	50	43	.88899070E+03
0 17	17	.84797760E+03	34	28	.87075480E+03	51	44	.89011230E+03

Policy in Tables 6.9a refers to the optimal quantity of water for the farmer to release from his CS for irrigation use in that season. This decision variable is dependent on the stage of the planning horizon and state of the resource. For example at state 1 policy is also 1 implying that no water is available hence no releases are made. As water becomes available say at state 42 of stage 13 Table 6.9a, where CS content is 82 per cent, the policy is 35, meaning 68 per cent of the CS content must be released to attain optimal returns.

The state of the reservoir and the policy pursued determines the returns that accrue to the farmer. For example, a 75 ha lucern, maize and wheat farmer on the Ramah Canal at Vanderkloof Dam at state 11, Table 6.9a, (i.e having a CS content of only 20 per cent) should follow policy 11. This dictates that all the water in the reservoir be used with the return of R 834 237,80 accruing to the farmer. On the other hand if the farmer is say at state 41, which corresponds to 80 per cent of CS content, the policy is 34 with a return of R 879 054,50 over the remaining 13 seasons in the planning horizon. This means at 80 per cent CS content with farmer having 13 seasons to the end of his planning horizon, 66 per cent of his CS content should be released for use. It is also evident that some amount of water is saved for future use.

The policies in Table 6.9a are optimal converged policies. These optimal converged policies are the optimal policies for a farmer to follow in a steady-state situation (i.e. when the end of the planning horizon is sufficiently distant that the number of stages (i.e. seasons in this case) remaining in the planning horizon has no impact on the optimal decision. On the other hand when the end of the planning horizon is sufficiently close, it requires policies to be taken from the output of the specific number of stages remaining in the planning horizon.

Table 6.9b. Water MVPs calculated from present value of expected optimal remaining returns in stage 13 for base case (lucern, maize and wheat) for farmers on Ramah Canal at Vanderkloof Dam, 2001

Optimal Return (R '000)		MVP (R/m^3)	MVP (R/m^3)
810.6333	813.0065	.1632	.16
813.0065	815.3015	.1578	.16
815.3015	817.6747	.1632	.16
817.6747	820.0478	.1632	.16
820.0478	822.4209	.1632	.16
822.4209	824.7941	.1632	.16
824.7941	827.1672	.1632	.16
827.1672	829.4915	.1598	.16

829.4915	831.8646	.1632	.16
831.8646	834.2378	.1632	.16
834.2378	836.6108	.1632	.16
836.6108	838.9841	.1632	.16
838.9841	841.0616	.1428	.14
841.0616	843.4348	.1632	.16
843.4348	845.6045	.1492	.15
845.6045	847.9776	.1632	.16
847.9776	850.1063	.1464	.15
850.1063	851.9028	.1235	.12
851.9028	853.2423	.0921	.09
853.2423	854.8340	.1094	.11
854.8340	856.5081	.1151	.12
856.5081	857.9260	.0975	.10
857.9260	858.8211	.0615	.06
858.8211	860.0815	.0867	.09
860.0815	861.2993	.0837	.08
861.2993	862.4852	.0815	.08
862.4852	863.6712	.0815	.08
863.6712	864.8571	.0815	.08
864.8571	866.0430	.0815	.08
866.0430	867.2289	.0815	.08
867.2289	868.4148	.0815	.08
868.4148	869.6007	.0815	.08
869.6007	870.7548	.0794	.08
870.7548	871.9390	.0814	.08
871.9390	873.1249	.0815	.08
873.1249	874.3108	.0815	.08
874.3108	875.4967	.0815	.08
875.4967	876.6827	.0815	.08
876.6827	877.8686	.0815	.08
877.8686	879.0545	.0815	.08
879.0545	880.2404	.0815	.08
880.2404	881.4263	.0815	.08
881.4263	882.6122	.0815	.08
882.6122	883.7219	.0763	.08
883.7219	884.7360	.0697	.07
884.7360	885.8002	.0732	.07
885.8002	886.7416	.0647	.06

886.7416	887.8047	.0731	.07
887.8047	888.9907	.0815	.08
888.9907	890.1123	.0771	.08

The first column of Table 6.9b reproduces the present value of expected optimal remaining returns in Table 6.9a correct to four decimal places. The second column shows the same values but arranged in the order that facilitates the calculation of the marginal returns (i.e. the difference in returns between two consecutive state intervals). The difference in returns between the values in the first two columns divided by the number of cubic meters of water in a state interval (for example the state interval for base case LMW is given by 2 per cent of 727 200 m^3, which is 14 544 m^3) gives the MVPs in column three. In column four the MVPs are rounded to two decimal places. The numbers in column four are taken to represent the values of additional units of water to the farmer producing lucern, maize and wheat and having 13 seasons to the end of the planning horizon. These values range between 8 and 16 cents per m^3 depending on the state of the farmer's CS and the optimal policy.

6.3.2.3 Sim 2 Output

The headings for the 11 columns in the Sim 2 output Table 6.9 are as follows.

Column 1 = S3, beginning-season farm CS contents as a percentage CS capacity)
2 = SFLOW, inflow into farm CS in 10^3m^3
3 = EVAP, seasonal evaporation from farm CS in 10^3m^3
4 = RELEAS, seasonal farm release from farm CS in 10^3m^3
5 = D1, optimal decision from SDP as a percentage of farm CS capacity.
6 = FRMREV, Gross Margin (GM) from releasing D1 (R'000)
7 = TOT, accumulated GM over two seasons per year (R'000)
8 = LT, season of the year, 1 = winter and 2 = summer.
9 = RESCONB, farm CS contents at the start of season in 10^3m^3.
10 = RESCONF, farm CS contents at season's end plus season's spills in 10^3m^3.
11 = RECEET, water received at farm = release less approximately half CS surface evaporation losses and dam-farm transmission losses in 10^3m^3.

Table 6.10 Sim II Output for 75ha farmer producing Lucern Maize and Wheat (base case) on the Ramah Canal at Vanderkloof Dam, 2001.

1	2	3	4	5	6	7	8	9	10	11
S3 %	SFLOW 10^3m^3	EVAP 10^3m^3	RELEAS 10^3m^3	DI %	FMREV R'000	TOT R'000	LT	RESCB 10^3m^3	RESCF 10^3m^3	RECET 10^3m^3
100.00	443.87	16.06	407.23	56.00	138.48	138.48	1.00	727.20	747.78	357.60
100.00	1521.15	77.59	625.39	86.00	71.41	209.89	2.00	727.20	1545.38	562.85
100.00	655.65	17.85	407.23	56.00	138.48	138.48	1.00	727.20	957.77	357.60
100.00	655.13	54.20	625.39	86.00	71.41	209.89	2.00	727.20	702.73	562.85
96.64	171.91	13.35	407.23	56.00	138.48	138.48	1.00	702.73	454.06	357.60
62.44	829.60	51.82	349.06	48.00	48.88	187.36	2.00	454.06	882.78	314.45
100.00	253.98	14.45	407.23	56.00	138.48	138.48	1.00	727.20	559.49	357.60
76.94	478.32	45.21	450.86	62.00	57.18	195.66	2.00	559.49	541.74	405.78
74.50	435.65	12.87	407.23	56.00	138.48	138.48	1.00	541.74	557.29	357.60
76.64	451.90	44.38	450.86	62.00	57.18	195.66	2.00	557.29	513.95	405.78
70.68	140.97	9.91	407.23	56.00	138.48	138.48	1.00	513.95	237.78	357.60
32.70	613.67	37.61	232.70	32.00	37.97	176.45	2.00	237.78	581.13	209.43
79.91	71.74	10.45	407.23	56.00	138.48	138.48	1.00	581.13	235.18	357.60
32.34	345.16	30.23	232.70	32.00	37.97	176.45	2.00	235.18	317.41	209.43
43.65	144.82	7.39	317.41	43.65	110.63	110.63	1.00	317.41	137.43	285.67
18.90	346.93	27.82	130.90	18.00	21.36	131.99	2.00	137.43	325.65	117.81
44.78	126.44	7.35	319.97	44.00	111.52	111.52	1.00	235.65	124.77	287.97
17.16	327.64	26.79	124.77	17.16	20.36	131.87	2.00	124.77	300.85	112.29
41.37	217.68	7.87	300.85	41.37	104.85	104.85	1.00	300.85	209.81	270.77
28.85	688.40	38.93	203.62	28.00	33.22	138.08	2.00	209.81	655.67	183.25
90.16	175.22	12.58	407.23	56.00	138.48	138.48	1.00	655.67	411.08	357.60
56.53	553.70	43.26	305.42	42.00	45.32	183.80	2.00	411.08	616.09	274.88
84.72	736.18	16.66	407.23	56.00	138.48	138.48	1.00	616.09	928.38	357.60
100.00	2519.68	104.55	625.39	86.00	71.41	209.89	2.00	727.20	2516.94	562.85
100.00	721.15	18.40	407.23	56.00	138.48	138.48	1.00	727.20	1022.72	357.60
100.00	1539.92	78.09	625.39	86.00	71.41	209.89	2.00	727.20	1563.65	562.85
100.00	455.49	16.15	407.23	56.00	138.48	138.48	1.00	727.20	759.31	357.60
100.00	426.46	48.03	625.39	86.00	71.41	209.89	2.00	727.20	480.23	562.85
66.04	390.34	11.45	407.23	56.00	138.48	138.48	1.00	480.23	451.90	357.60
62.14	728.01	48.97	349.06	48.00	48.88	187.36	2.00	451.90	781.88	314.15
100.00	196.12	13.96	407.23	56.00	138.48	138.48	1.00	727.20	502.13	357.60
69.05	539.06	48.97	407.23	56.00	53.62	192.90	2.00	502.13	588.98	366.51
80.99	108.10	10.89	407.23	56.00	138.48	138.48	1.00	588.98	278.96	357.60
38.36	296.25	30.46	261.79	36.00	41.76	180.24	2.00	278.96	283.16	235.61
38.94	240.84	7.97	276.34	38.00	96.31	96.31	1.00	283.16	239.69	248.70
32.96	688.49	39.74	232.70	32.00	37.97	134.28	2.00	239.69	655.73	209.43
90.17	45.85	11.49	407.23	56.00	138.48	138.48	1.00	655.73	282.86	357.60
38.90	267.21	29.88	261.79	36.00	41.76	180.24	2.00	282.86	258.40	235.61

Using 19 years of simulated data the model in Sim 2 simulates the use of optimal SDP decisions for 19 years (i.e. 38 seasons) as expressed in Table 6.10,

- the farmer's CS contents;
- streamflows and evaporation;
- quantity of water to release and water release decisions to follow;
- farm revenue both seasonal and annual;
- reservoir CS contents at the beginning and the end of each season; and
- water releases less transmission losses.

The first row of this table for example refers to the very first winter in the 19 years considered. Starting with a 100 per cent CS content, streamflows to the farmer's capacity share is 443 870 m^3, when 16 060 m^3 is lost through evaporation. The optimal amount of water to release comes from the output of the SDP model. For this state and stage, it is 407 230 m^3 of water, which forms 56 per cent of his CS share. From this decision a gross margin of R138 480 is obtained for winter. The farmer is assumed to have started with 100 per cent CS content, meaning the reservoir CS content at the start of the season is 727 200 m^3. The farmer ended up the season with a reservoir CS content plus spills of 747 780 m^3, which shows that a 100 per cent reservoir CS content is guaranteed at the beginning of the summer season. Considering this content and projecting for new inflows the farmer follows a different SDP decision in summer. Being a different season, crop water requirements as well as the revenue generated are different. The second row provides these values, and their explanation follows in the same way as for winter, which was discussed earlier. The table therefore summarises what the farmer's sequence of water supply will be in the next 19 years to follow and the gross margins the farmer will receive by following SDP optimal decisions.

6.3.3 MVPs FROM SDP FOR INTER-SEASON DECISIONS FOR 75 HA FARM.

Unlike the MVPs obtained from LP which reflect what a farmer can pay for marginal units of water delivered onto the farm during the immediate season, MVPs in this case of SDP are for inter season comparisons. They are once-off payments or values for a marginal unit of water to use anytime in the future. More specifically, they are the expected values of marginal units of water in the farmer's reservoir CS. Ten scenarios as below were investigated for two different crop mixes: lucern, maize and wheat (LMW); and potato, maize and wheat (PMW).

Scenario 1 - Base case (BC) (100% of CS and inflow shares (IS))

The size of the farmer's reservoir capacity share (CS) is chosen so that the maximum content of the CS is just sufficient to maximize the farm gross margin in the season of the highest demand, which is the summer season in this case. The size of the inflow shares (IS) for the base case (BC) is also chosen so that the mean seasonal inflow share is equal to the quantity of water required to maximise the farm gross margin Reservoir evaporation and seepage losses, and dam-to-farm transmission losses are not considered when determining these CS and IS sizes. The following arbitrarily selected scenarios with respect to the base case are identified;

Scenario 2 - CS and IS are75% of BC.
Scenario 3 - CS and IS are 50% of BC.
Scenario 4 - CS and IS are 25% of BC.
Scenario 5 - CS same as BC but IS doubles.
Scenario 6 - CS same as BC but IS only 50% of BC.
Scenario 7 - CS is 50% of BC but IS are the same.
Scenario 8 - CS and IS are double that of BC.
Scenario 9 - CS and IS are triple that of BC.
Scenario 10 - CS and IS are quadruple that of BC.

The results of LMW are presented graphically in Figures 6.7 to 6.16. Each of these figures contain two sections or parts; an upper part, showing the SDP-derived MVPs, and a lower part showing the SDP-derived optimal release decisions from the farmer's reservoir CS. The two-part figures show four MVPs and two decisions. The four MVPs are: MVP from the last season (summer) in the planning horizon, labelled X//1; MVP from the second-last season (winter) in the planning horizon, labelled X//2; MVP from the season (summer) when 13 seasons remain in the planning horizon labelled X//13 and MVP from the winter season when 14 seasons remain, labelled X//14. X refers to the scenario number. The two sets of decisions are optimal water releases for the summer season with 13 seasons remaining in the planning horizon and similarly for the winter season when 14 seasons remain.

6.3.3.1 MVPs for Lucern/ Maize-Wheat (LMW) Scenarios

First, the Figures 6.5 and 6.7 will be compared before investigating the identified scenarios. Comparing Figures. 6.5 and 6.7 reveals the following: For the summer crops there are three main distinctions;

- The LP MVP in Figure 6.5 is 0.18 and 0.09, whereas the SDP MVP in the upper section of Figure 6.7 is 0.16 and 0.08, due to transmission and reservoir losses. That is, these losses in and between dam and farm cause the MVP of water in the reservoir to be less than the MVP of water delivered to the farm.
- For the same reasons, the quantity of reservoir water with MVP of 0.16 in Figure 6.7 is greater than the quantity of water received at the farm in Figure 6.5 with MVP of 0.18. That is, the implicit sharp step down in Figure 6.5 occurs at a lesser quantity of water than the step down in Figure 6.7.
- The step is sharp in the LP output because the LP MVPs are for the precise maximum quantity of water for the higher value crop lucern, and the lower value crop (maize) MVP begins at that precise point. In contrast, the last of the 0.16 MVP values in Figure 6.7 occurs at less than the maximum water required for the higher value crop. Hence the next observation for the last year of the planning horizon is between the upper 0.16 MVP and the lower 0.08 MVP. That is, the discrete 2 per cent increments in the reservoir CS contents state variable do not precisely coincide with the maximum water required by the high value crop.

Concerning the single winter crop;

- The LP MVP of 0.39 again exceeds the SDP MVP of 0.35, for the above reasons. Again for the same reason, the high SDP MVP in Figure. 6.7 extends to a larger volume of water than that for the LP MVP.
- Furthermore, the LP MVP has no step, whereas the SDP MVP does. The reason being that, the SDP MVP covers both of the remaining two seasons, so the CS contents in excess of the immediate winter-crop requirements can be carried

forward to the one remaining (summer) season in the planning horizon. Because the probability of inflows is non-zero, the SDP MVP at the start of the winter season for water exceeding the immediate winter-crop requirements, and hence carried forward (with losses) to the summer season, is less that the 0.16 that it would approach if the probability of inflows during the winter was zero. As the carryover to the summer season increases, the SDP MVP decreases more-or-less steadily, reflecting the diminishing role of carryover water with non-zero inflows. It becomes less that the 0.08, following this same general tendency. If the winter season was the last in the planning horizon, or if the probability of the reservoir filling during the winter was one, then the winter SDP MVP would plunge to zero once the winter crop requirements were met.

Scenario 1 (Base case) LMW - Figure 6.7

- In Figure 6.7 the cut-off point along the horizontal axis for the base case is approximately 727 200 m^3. This is derived from the LP and represents 100 per cent of CS content. The horizontal distance between successive points (i.e. square, cross, diamond, triangle) in Figure 6.7 represents 2 per cent of 727 200 m^3, or 14 544 m^3
- The MVP for summer season water at the start of the last summer in the planning horizon (1//1) seem to be the same as when 13 seasons remain in the farmer's planning horizon (1//13). This in evident from the high similarity between the respective MVP curves. Beside the few fluctuations on the 1//13 curve, the MVPs can be taken as R 0,16 per cubic meter when the CS content is about a third. Beyond a third to full CS capacity, MVP drops by about half to R 0,08 per cubic meter. Although irregular, there appears to be a slight, persistent tendency for the SDP MVPs of reservoir CS water at the start of the summer season for a long planning horizon to exceed that for the one-season-long planning horizon when the reservoir CS contents exceeds that required for lucern. This implies that higher MVPs could only result from saving water from summer maize for use in

future seasons. This saving is indicated, although with some irregularity for the same range of reservoir CS content, in the lower part of Figure 6.7.

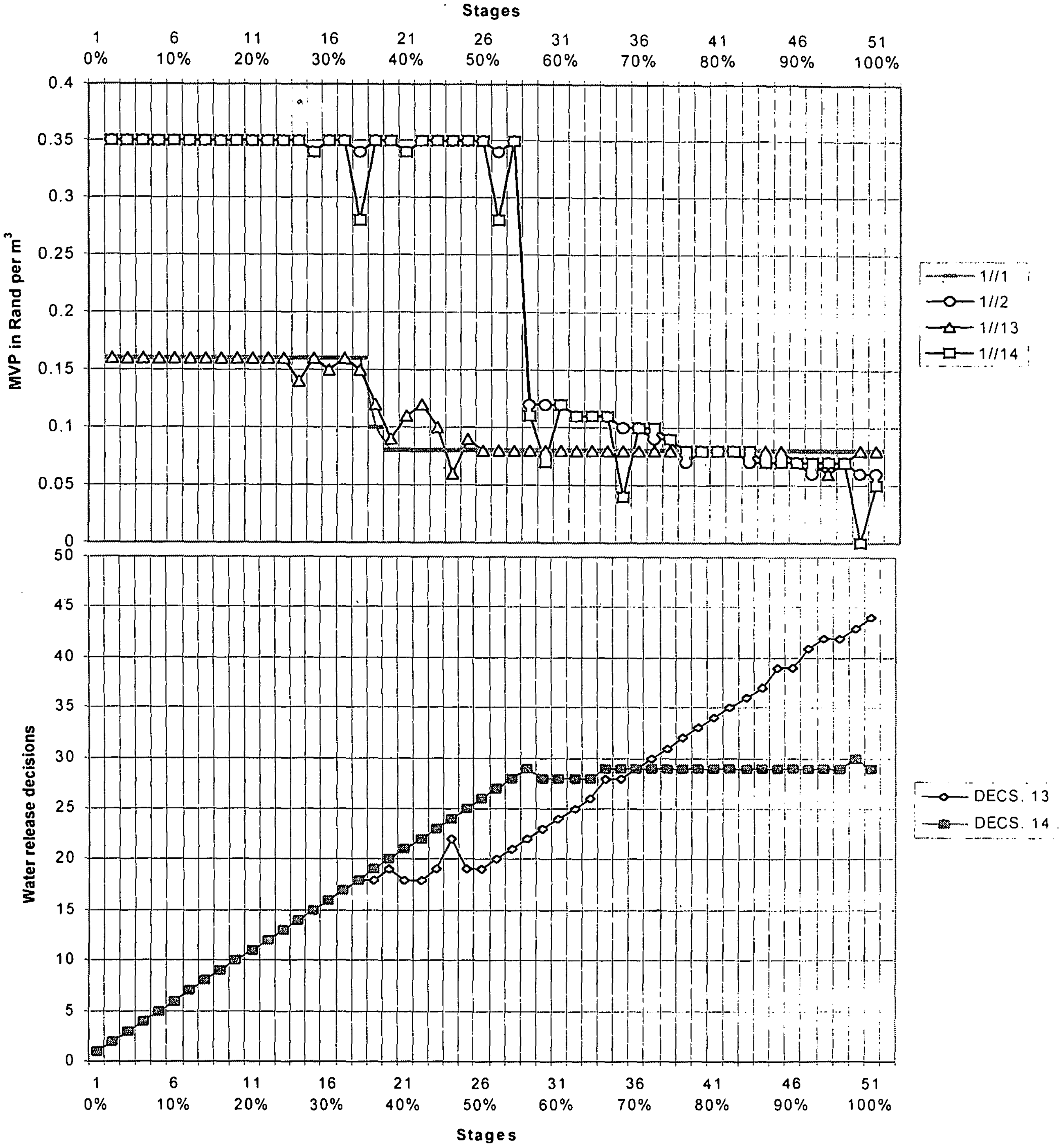


Figure 6.7: **MVP in Rand per m^3 and optimal water release decisions for the Base Case (LMW) scenario**

- The MVP curves for the two winter curves (1//2 and 1//14) are also highly similar. Irrespective of the seasons remaining in the farmer's planning horizon, MVPs are R 0,35 per cubic meter when CS content is about 50 per cent and decline sharply hovering between R 0,12 and R 0,06 per m^3 for CS content above 50 per cent.
- The lower part of Figure 6.7 also shows that all available reservoir CS water is applied to wheat in winter until its maximum area is grown, then no more. That is, all available water is applied to wheat until its MVP (in the upper part of Figure 6.7) drops dramatically. Any additional water is saved.
- For summer lucern, all available water is released until the maximum amount is grown, then variable quantities of water saving takes place until about 102 000 m^3 is saved. Then water is applied to maize but the quantity saved for future seasons remains approximately constant at about 14 per cent (102 000 m^3) of the farmer's reservoir capacity.

Scenario 2 (CS and 1S 75% of BC) LMW - Figure 6.8

- The cut-off point along the horizontal axis in this case is approximately 545 400 m^3, 75 per cent of that in the base case. The horizontal distance between any two successive points on a curve in Figures 6.8 is 10 908 m^3 (i.e. 2 per cent of 545 400 m^3)
- The MVPs for the last summer in the planning horizon show little change from the base case, but those for the long planning horizon, although rather irregular, do show a marked persistence to exceed those for the one-season planning horizon when sufficient water is available to irrigate the maximum lucern area but only some maize. This suggests foregoing maize and saving water for future seasons over this range of reservoir CS contents. The lower portion of Figure 6.8 shows marked summer water saving over this range of water availability.
- The number of seasons remaining in the planning horizon has virtually no impact on winter MVPs.

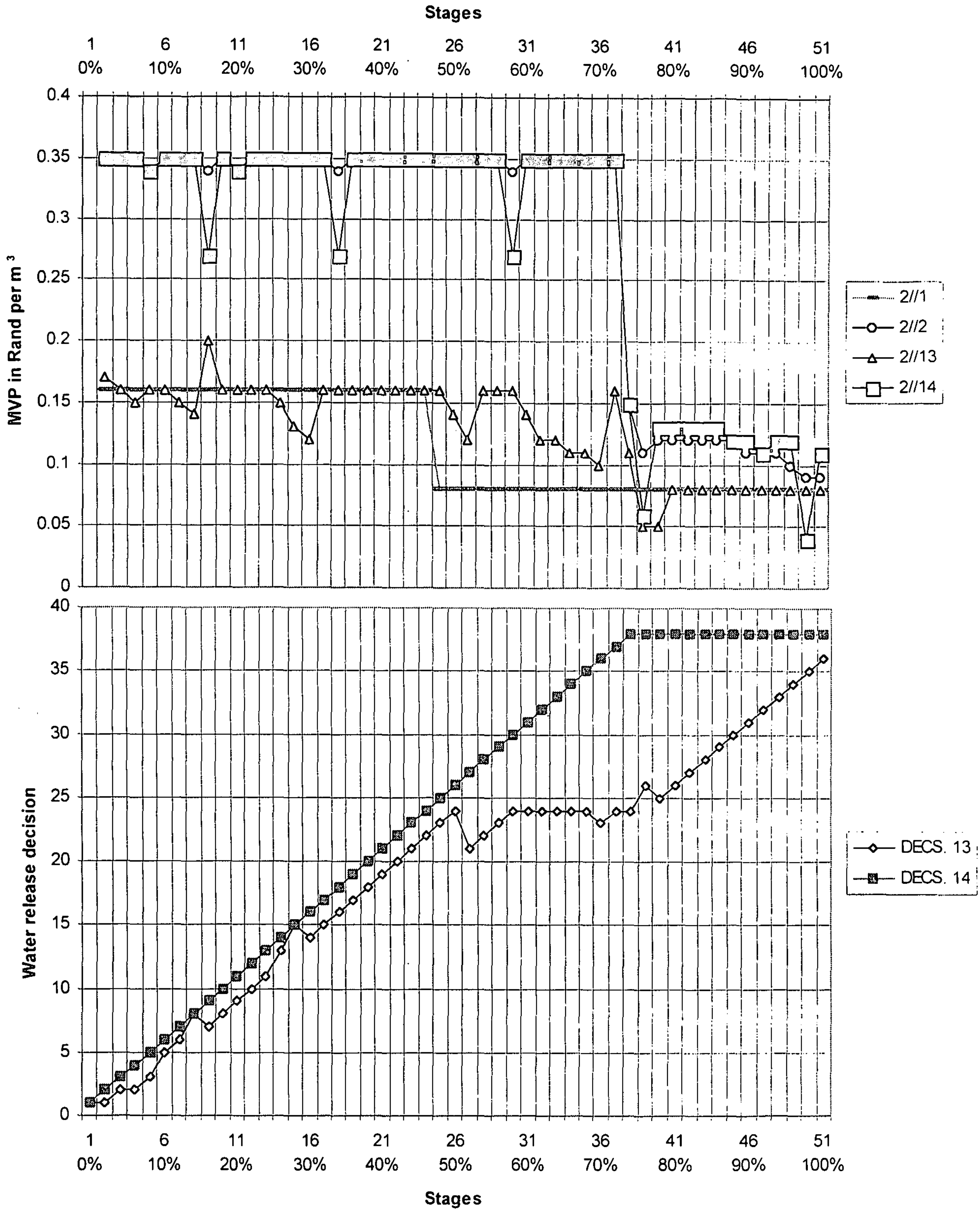


Figure 6.8: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 75% of Base Case (LMW)

- The lower portion of Figure 6.8 also shows minor water saving on lucern but major water saving on maize until available reservoir CS water reaches higher levels, as indicated above.

Scenario 3 (CS and IS 50% of BC) LMW - Figure 6.9

- In this case the cut-off point along the horizontal axis is approximately 363 600 m^3 50 per cent of that in base case. The horizontal distance between any two successive points on a curve in Figures 6.9 is 7272 m^3 (i.e. 2 per cent of 363 600 m^3).
- Winter MVPs (3//2 and 3//14) remain essentially the same as in base case, with number of seasons left in the planning horizon having limited impact.
- For the summer season with a long planning horizon (3//13), water at CS content of less than 87 264 m^3 has higher MVPs than the MVP of water applied to lucern. This results in no lucern being irrigated in the immediate season until the reservoir CS contents exceeds this amount, as shown in the lower portion of Figure 6.9. Thereafter water is released approximately as it becomes available.

- The lower part of Figure 6.9 also shows that no water saving occurred in the winter season. The consistent high MVPs in the upper portion of the same figure show evidence of water not being enough for use in the immediate season.

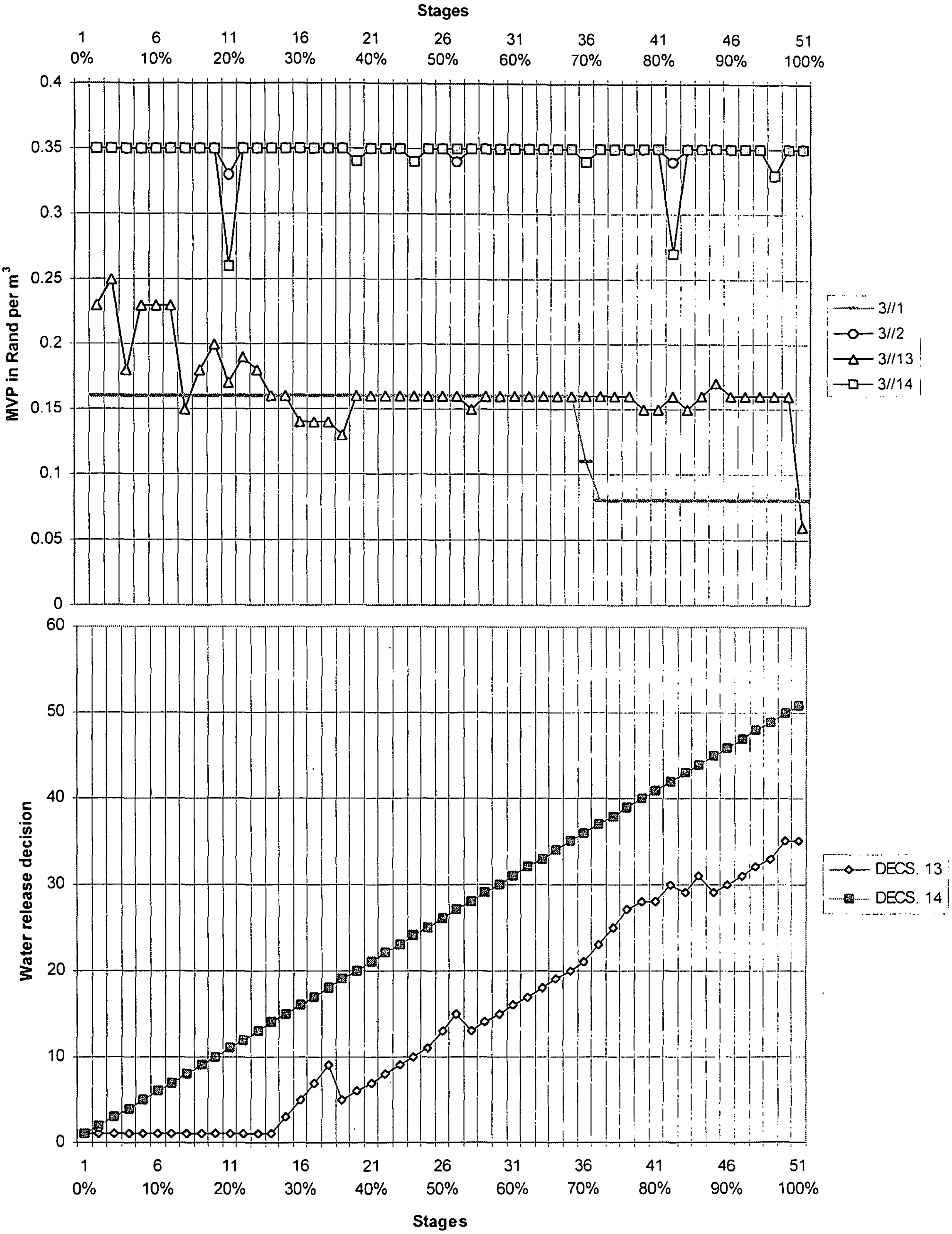


Figure 6.9: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 50% of Base Case (LMW)

Scenario 4 (CS and IS 25% of BC) LMW - Figure 6.10

- In Figure 6.10 the cut-off point along the horizontal axis is approximately 181 800 m^3. The horizontal distance between any two successive points on a curve in Figures 6.10 is 3636 m^3 (i.e. 2 per cent of 181 800 m^3).
- Winter MVPs (4//2 and 4//14) essentially assume only one value, that is R 0,35 per cubic meter, regardless of the seasons left in the planning horizon.
- Because the water available is now insufficient to irrigate the maximum area of lucern, the 4//1 MVPs are R 0,16 per cubic meter. The long planning horizon MVPs for summer (4//13), although irregular, are usually higher than the 4//1 MVPs when reservoir CS contents are less than approximately 61 000 m^3. This indicates that water should be saved and no summer crop grown until reservoir CS contents exceed this quantity, which is generally borne out by the lower portion of Figure 6.10. The few examples of water usage over this range of reservoir CS contents correspond to the 4//13 MVPs that are less than or equal to the 4//1 MVPs in the upper portion of Figure 6.10.
- As in scenario 3, the lower portion Figure 6.10 shows no water saving occurred in the winter season. No water savings imply that, the immediate season's requirements are not, or only just, met due to water scarcity.

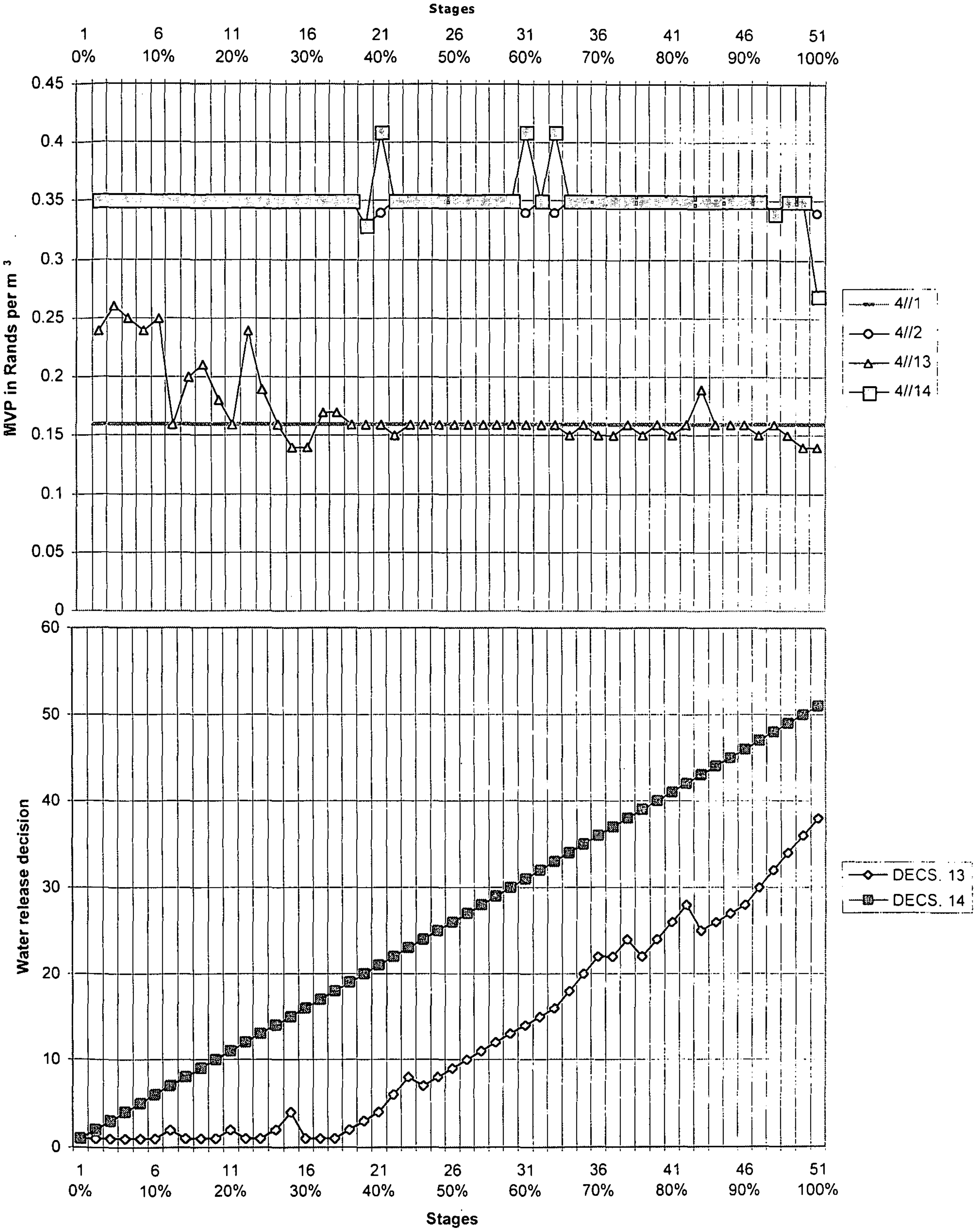


Figure 6.10: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 25% of Base Case (LMW)

Scenario 5 (CS same as BC but IS doubles) LMW - Figure 6.11

- The MVPs for this case, upper Figure 6.11, are quite similar to those for the base case in Figure 6.7.
- Summer MVPs for the last season in the planning horizon are identical to the base case, but those for 13 seasons remaining no longer show MVPs with the persistent tendency to exceed those from maize when reservoir CS contents are only a little greater than the lucern requirements. This would be due to the increased inflows to the reservoir CS.
- Apart from the irregularities, the winter MVPs are the same as in the base case until water availability exceeds the wheat requirements. Then the water MVPs fall below the summer ones, again due to the increased inflows.
- No water saving occurs in the lower part of Figure 6.11 except in winter when supply exceeds maximum wheat requirements. This is similar to the base case. However, unlike the base case, no summer saving occurs because of the increased inflows.

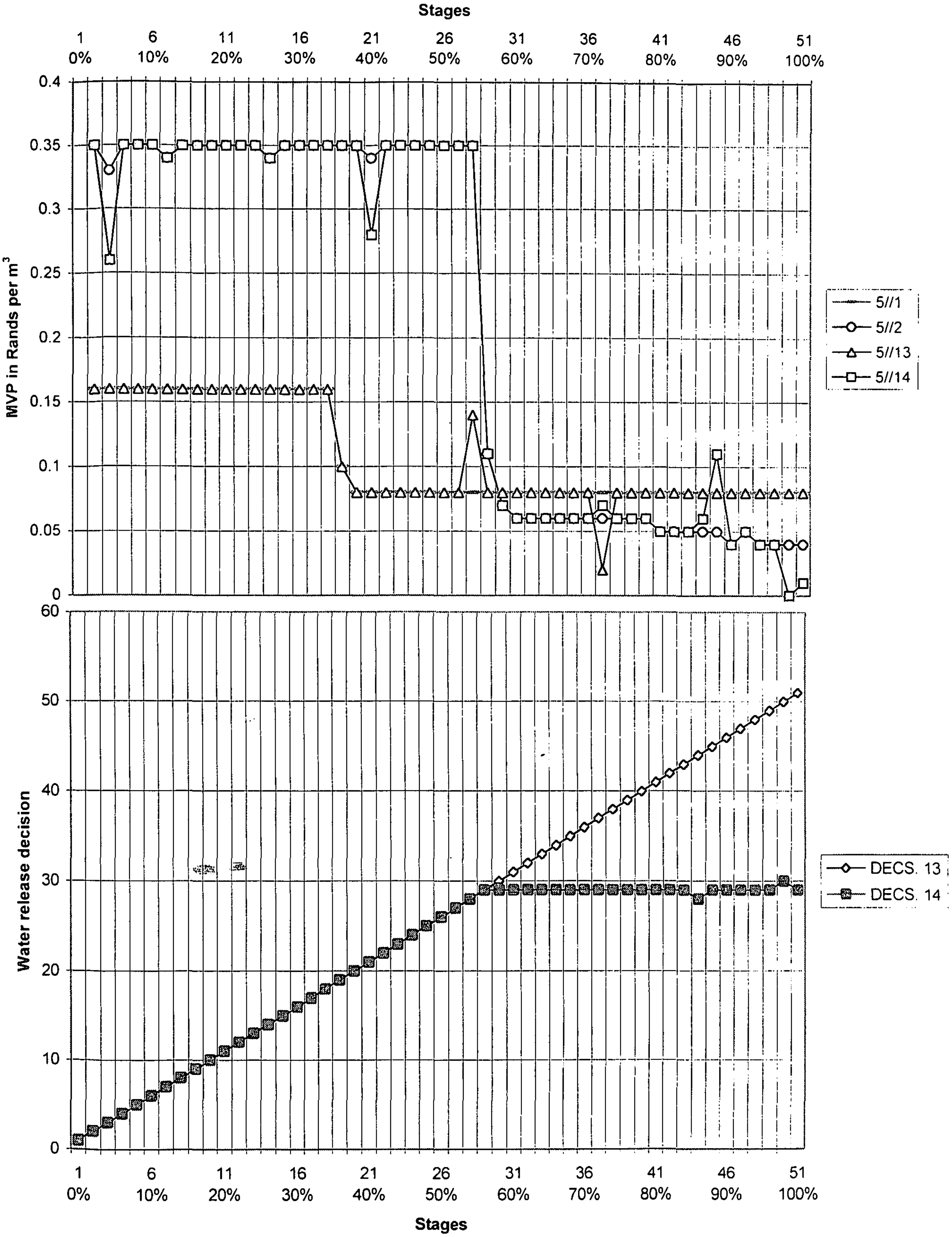


Figure 6.11: MVP in Rand per m^3 and optimal water release decisions when CS equals Base Case and IS is 200% of Base Case(LMW)

Scenario 6 (CS same as BC but IS halves) LMW - Figure 6.12

- MVPs of R0.35 per m^3 for winter reservoir CS contents not exceeding wheat requirements, and R 0.15 and R 0.08 for summer, as in the base case, are apparent in the upper part of Figure 6.12. The winter MVPs for reservoir CS contents exceeding wheat requirements are somewhat higher than the base case when only 2 seasons remain in the planning horizon (6//2), and considerably higher when many seasons remain (6//14). This reflects the reduced inflows.
- With many seasons left in the planning horizon, the summer MVPs (6/13) are irregular but considerably exceed the MVPs from lucern until the lucern requirement is met. For larger quantities the MVPs considerably exceed the MVPs from maize.
- Comparison of the lower and upper portions of Figures 6.12 shows that the quantity of water required to grow the maximum area of lucern is first saved for use in future seasons. Larger reservoir CS contents would be used for growing lucern until the maximum quantity can be grown. Then the approximately level "step" indicates the saving of further water until the summer MVP line (6//13) intersects the MVPs from growing maize (6//1), indicating that further water in the reservoir CS should be used for growing maize in the immediate season. The final upward segment of decisions 13 in the lower potion of Figure 6.12 depicts this.

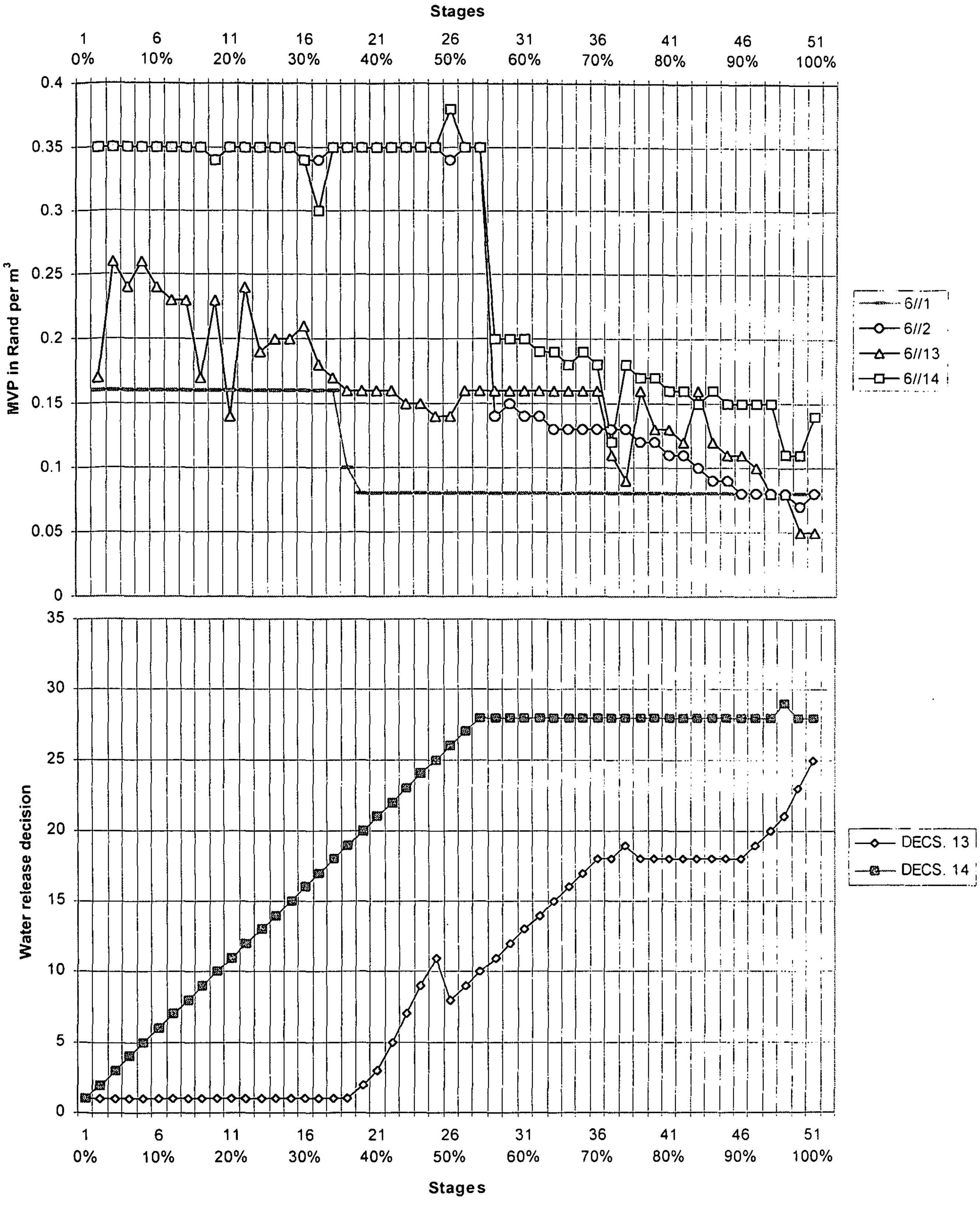


Figure 6.12: MVP in Rand per m^3 and optimal water release decisions when CS equals Base Case and IS is 50% of Base Case (LMW)

Scenario 7 (IS same as BC but CS halves) LMW - Figure 6.13

- The cut-off along the horizontal axis in this case is 363 600 m^3.
- There is very little difference between the MVPs for different planning horizons. The MVPs shown in the upper part of Figure 6.13 are very similar to the short planning horizon ones in the base case, but truncated at the reservoir CS capacity of 363 600 m^3 instead of 727 200 m^3.
- Water is in such short supply that MVPs from water saving do not exceed those from current irrigation except for two outliers. The lower part of Figure 6.13 shows that all available water is applied to wheat, regardless of the amount available up to reservoir CS capacity. However, some saving of summer water takes place by refraining from irrigating any maize until four 2 per cent (of 363 600 m^3) units of water are saved. Then as reservoir CS contents increase further, the additional water plus some of the previously saved water is used on maize until all of the saved water is used.
- Strict interpretation of the lower section of Figure 6.13 shows saving occurs twice more as reservoir CS contents increase further, but each time the saved water is used up as reservoir CS contents increase still further. Probably a more practical interpretation of the computer output in the same section of Figure 6.13 would be to save no water at any reservoir CS level.

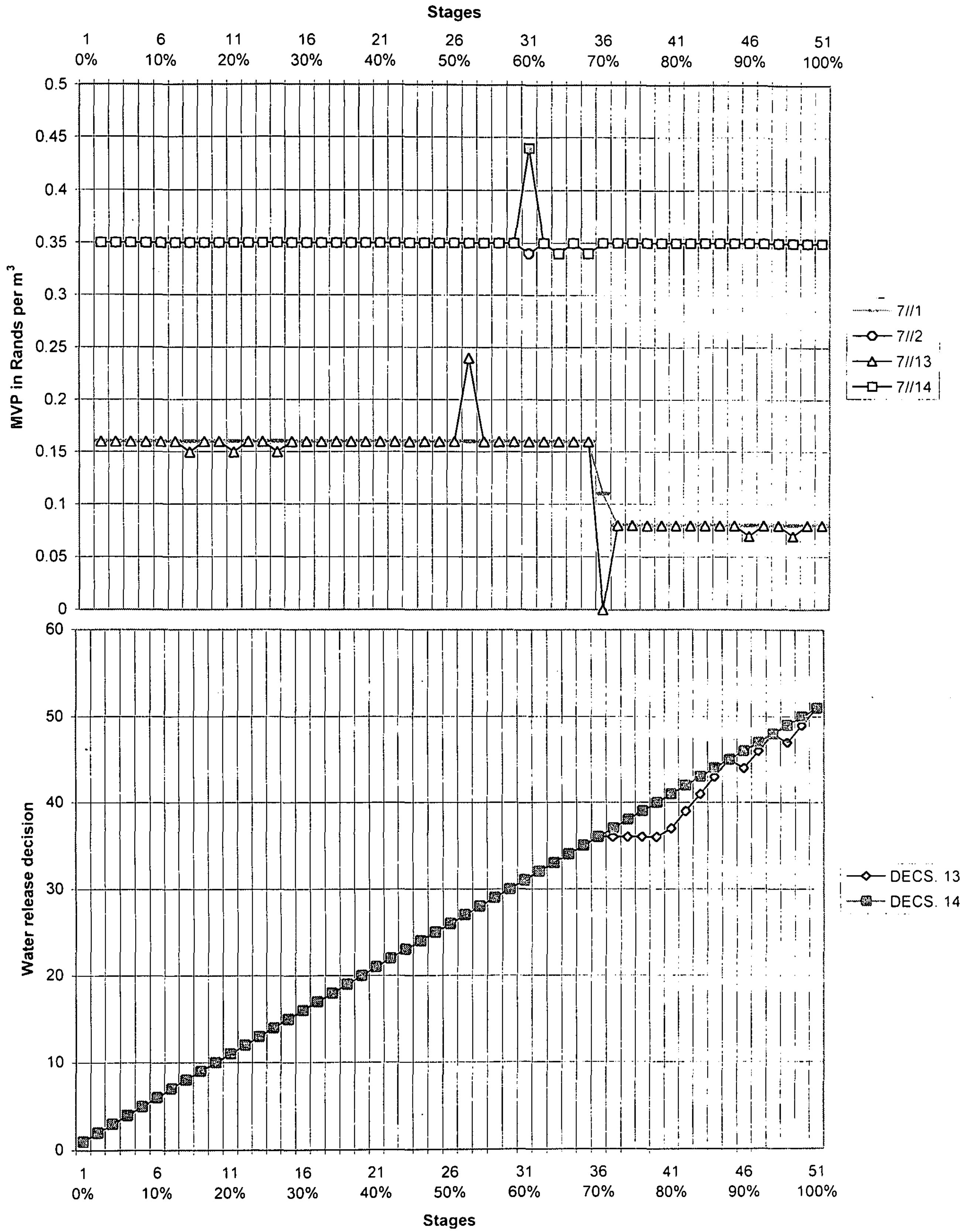


Figure 6.13: MVP in Rand per m^3 and optimal water release decisions when IS equals Base Case and CS is 50% of Base Case (LMW)

Scenario 8 (CS and IS double BC) LMW - Figure 6.14

- MVPs are similar to that of base case, when CS contents are within current season's requirements.
- Beyond season's requirements, very low MVPs in the vicinity of R 0,05 and below are recorded irrespective of the season or the number of seasons left in the planning horizon.
- From about 1200 000 m^3, MVPs become completely zero as the maximum quantity of water farmer can use and/or save profitably is exceeded.
- No savings were made when farmer's reservoir contents are within limits of season's requirements, as shown in the lower portion of Figure 6.14. Beyond these however, savings were recorded until all MVPs fall to zero.

Scenario 9 (CS and IS triple BC) Figure 6.15 and Scenario 10 (CS and IS quadruple BC) Figure 6.16 LMW

The upper portion of Figure 6.16, follows the same explanation as in scenario 8 above. Regarding water use as in the lower section of Figures 6.15 and 6.16, no observable savings are noticed in summer. In winter it is observed that water is saved only when the season's requirements are met and MVPs exceed zero but storage space is huge. Beyond approximately twice the base case capacity, water is released as spills since no economic value is attached to it.

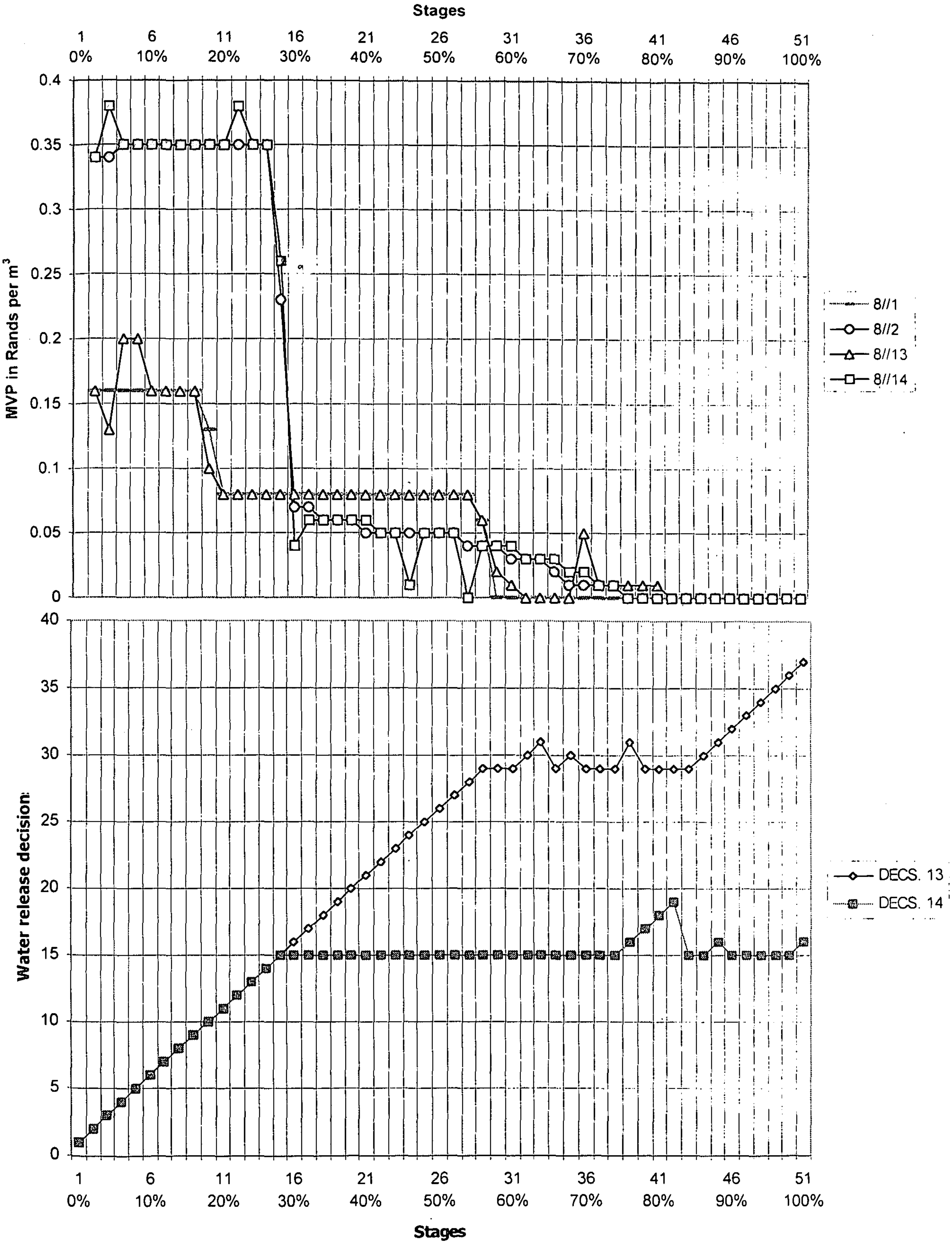


Figure 6.14: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 200% of Base Case (LMW)

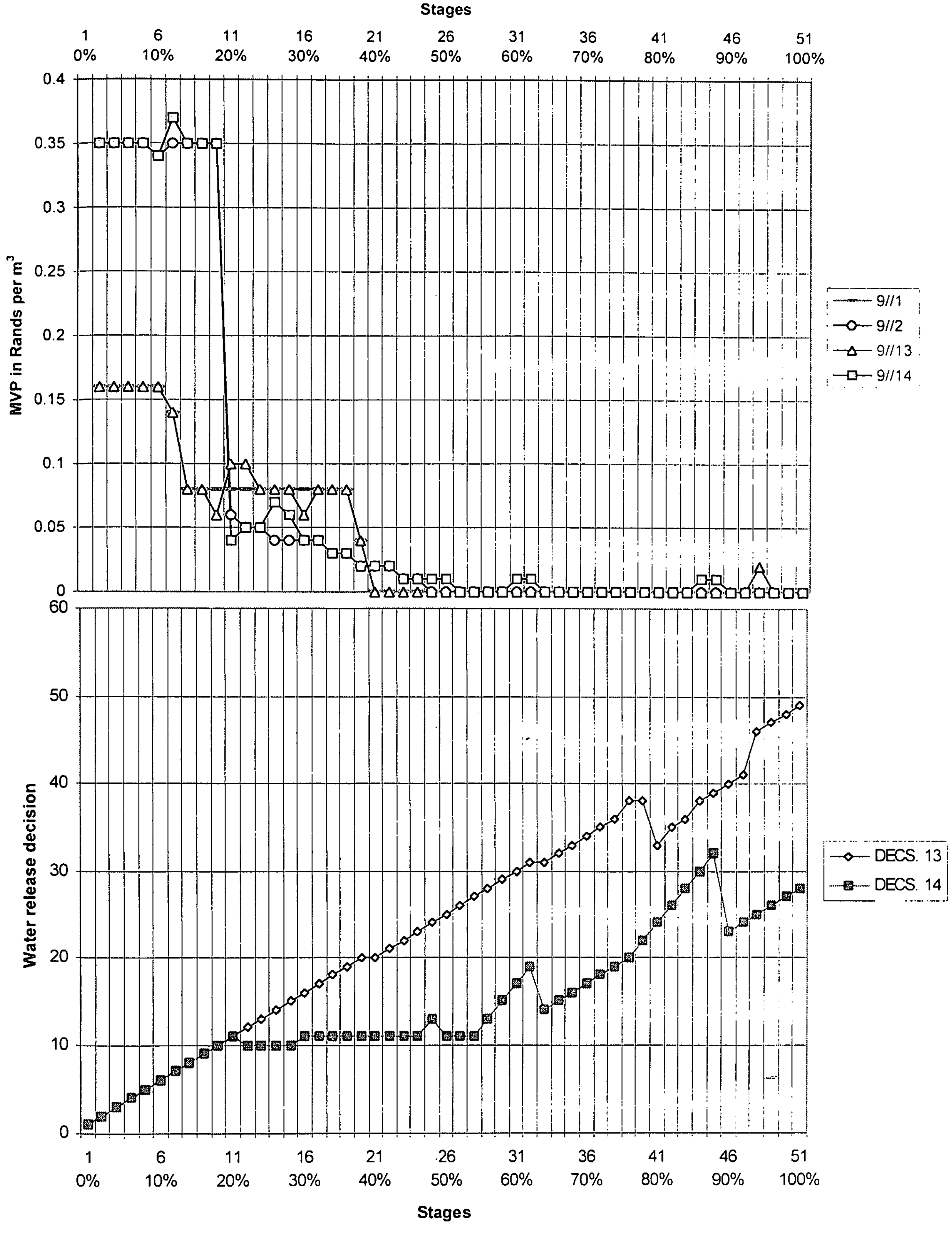


Figure 6.15: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 300% of Base Case (LMW)

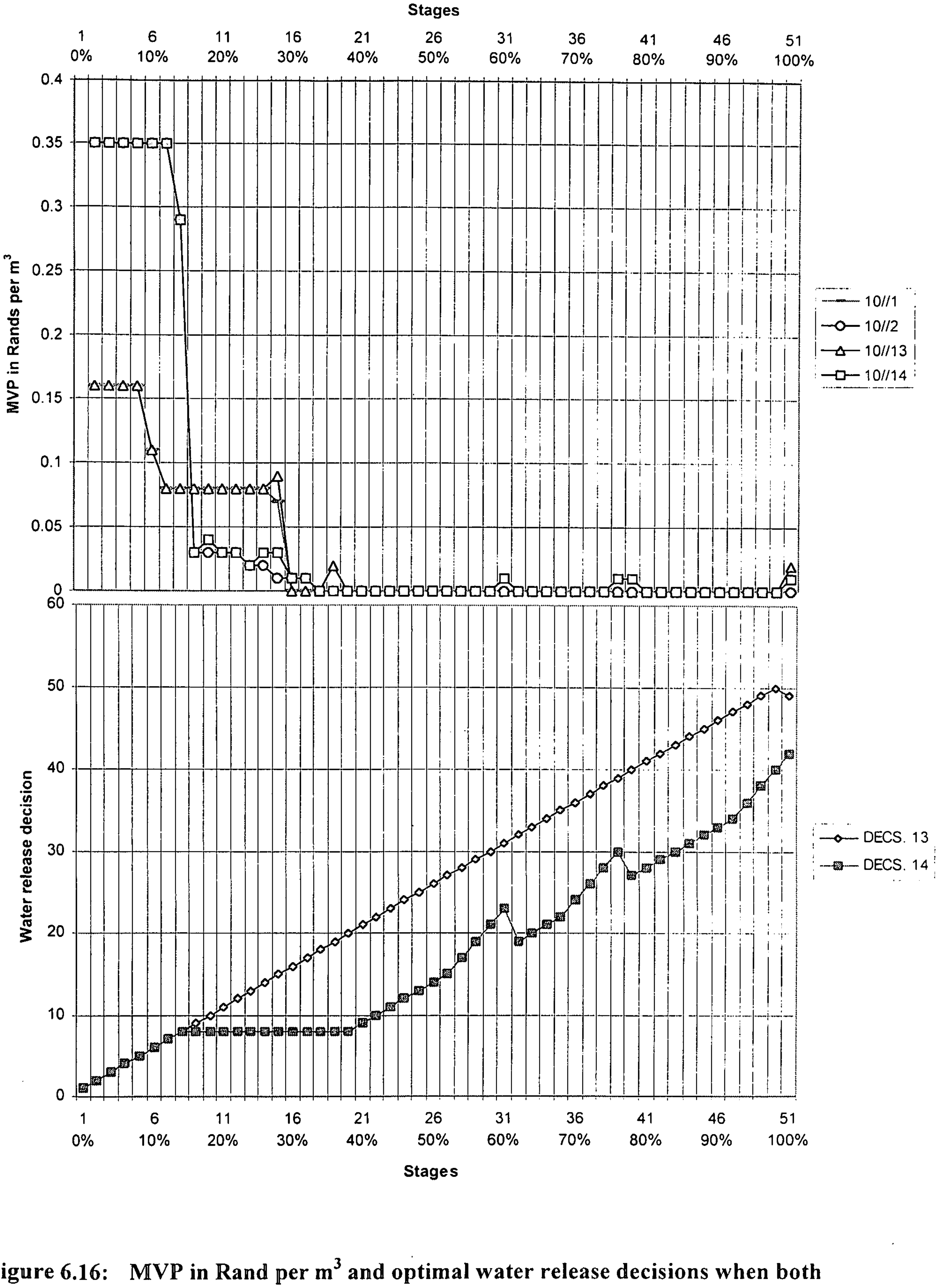


Figure 6.16: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 400% of Base Case (LMW)

6.3.3.2 MVPs for Potatoes/Maize-Wheat (PMW) Scenarios.

First, Figure 6.6 and the upper part of 6.17 are compared before investigating the identified scenarios. Comparing these two figures revealed the same points as made for the LMW case for very similar reasons.

In similar graphical analysis, for potato, maize and wheat (PMW) crop mix the following observations were made.

Scenario 1 (Base case) PMW - Figure 6.17

- Representing 100 per cent of CS content and 100 per cent of inflow share is the base case, which is approximately 568 950 m^3 (the cut-off point along the horizontal axis of Figure 6.17).
- MVPs for summer season irrespective of seasons remaining in the planning horizon show very little or virtually no differences between them. The MVP curves (1//1 and 1//13) depict this. Numerically most MVPs are R3.50 per m^3 when the CS content is up to 68 247 m^3 or about 12 per cent of capacity. Beyond this point up full capacity the MVPs drop sharply. Maize MVPs show some irregularity about R 0,08 per m^3.
- The wheat MVP curves for the two winter seasons (1//2 and 1//14) are also very similar. Despite the seasons remaining in the farmer's planning horizon, MVPs are approximately R 0,35 per m^3 for CS content of zero to about 410 000 m^3 after which it drops and equals summer MVPs of R 0,08 per m^3.
- The lower section of Figure 6.17 shows that, as reservoir CS contents increase, some limited water saving is optimal in winter until the maximum possible area of wheat is irrigated. Also further increases in reservoir CS contents are saved.
- In summer, no water saving occurs until the highly profitable potato crop reaches its maximum possible area (lower section Figure 6.17). Water saving is then irregular as beginning-season reservoir CS contents increase until they reach about 239 000 m^3. Further increases are to be allocated to maize with only limited saving when the reservoir CS is about 80 per cent full.

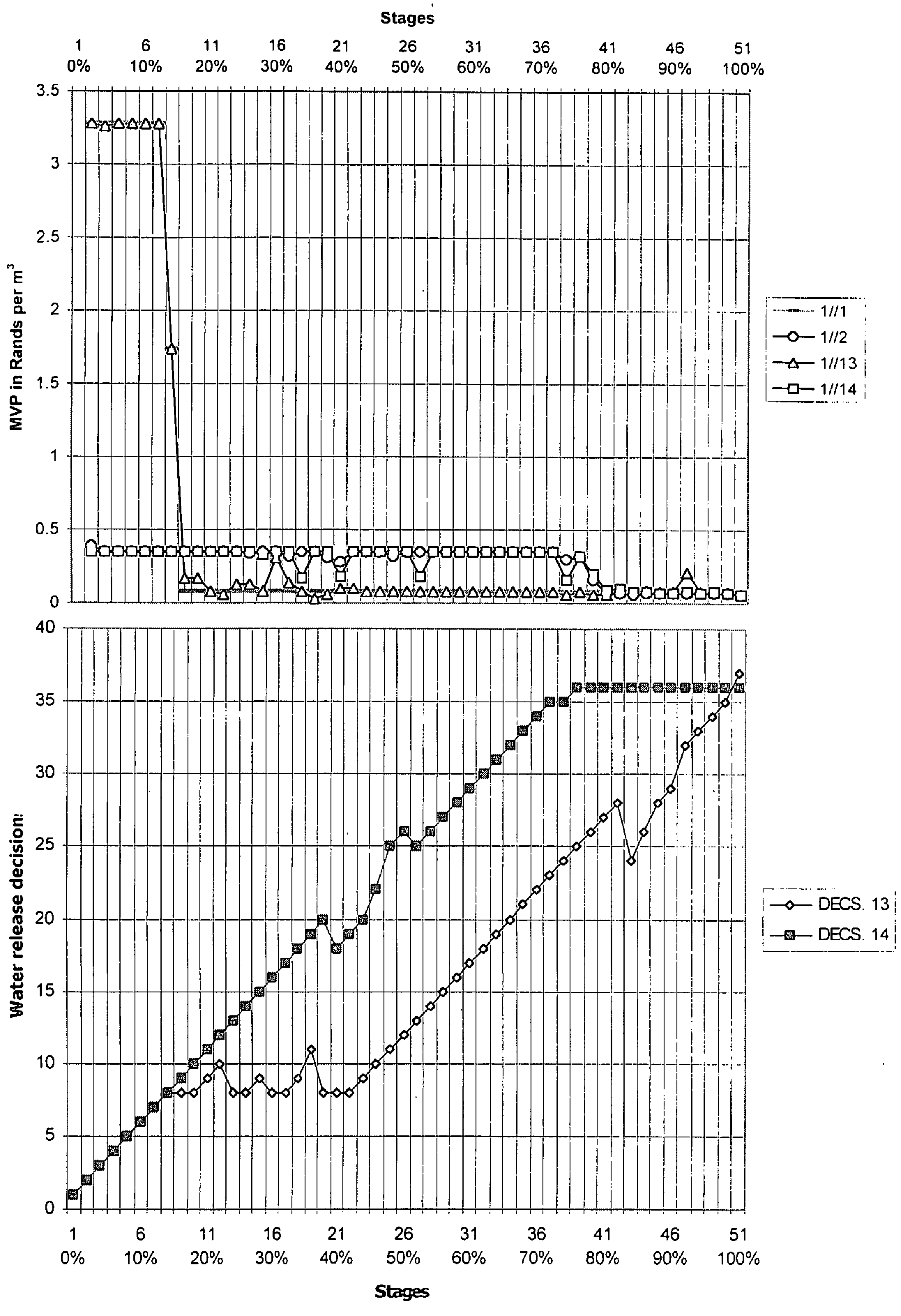


Figure 6.17: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are equal to Base Case (PMW)

- At low CS content (Figure 6.17) no water saving occurred in both winter and summer seasons. Water is used as becomes available. Winter water saving however, becomes marked when reservoir CS content is about 75 per cent and the season's requirements are adequately met.

Scenario 2 (CS and 1S 75% of BC) PMW - Figure 6.18

- In Figure 6.18, the cut-off point on the horizontal axis is 426 713 m^3.
- Summer MVPs behave in a similar manner to the base case, but with mostly higher long-planning-horizon MVPs (2//13) than for final-year maize (2//1) when reservoir CS contents range up to about 256 000 m^3.
- In winter MVPs show a gradual decline from zero CS content to 34 137 m^3 and thereafter shows some irregularity about R 0.35.
- With water becoming scarce, winter water saving started right from the very low end of the reservoir CS content as shown in the lower portion of Figure 6.18. It shows winter water saving approximately corresponding to the initial declining MVPs in the upper section of Figure 6.18, then maintaining that amount of saving throughout except for temporary increased use corresponding to the dips in MVPs below R0.35.
- Summer water saving only began from 76 806 m^3 CS content after the potato crop was adequately provided for. Water saving then occurred for larger reservoir CS contents, corresponding to the points in the upper section of Figure 6.18 for which the long-planning horizon MVPs (2//13) are greater than the maize MVPs (2//1). That quantity of water continues to be saved throughout (lower section Figure 6.18) except when the long-planning-horizon MVPs are less than the maize MVPs.

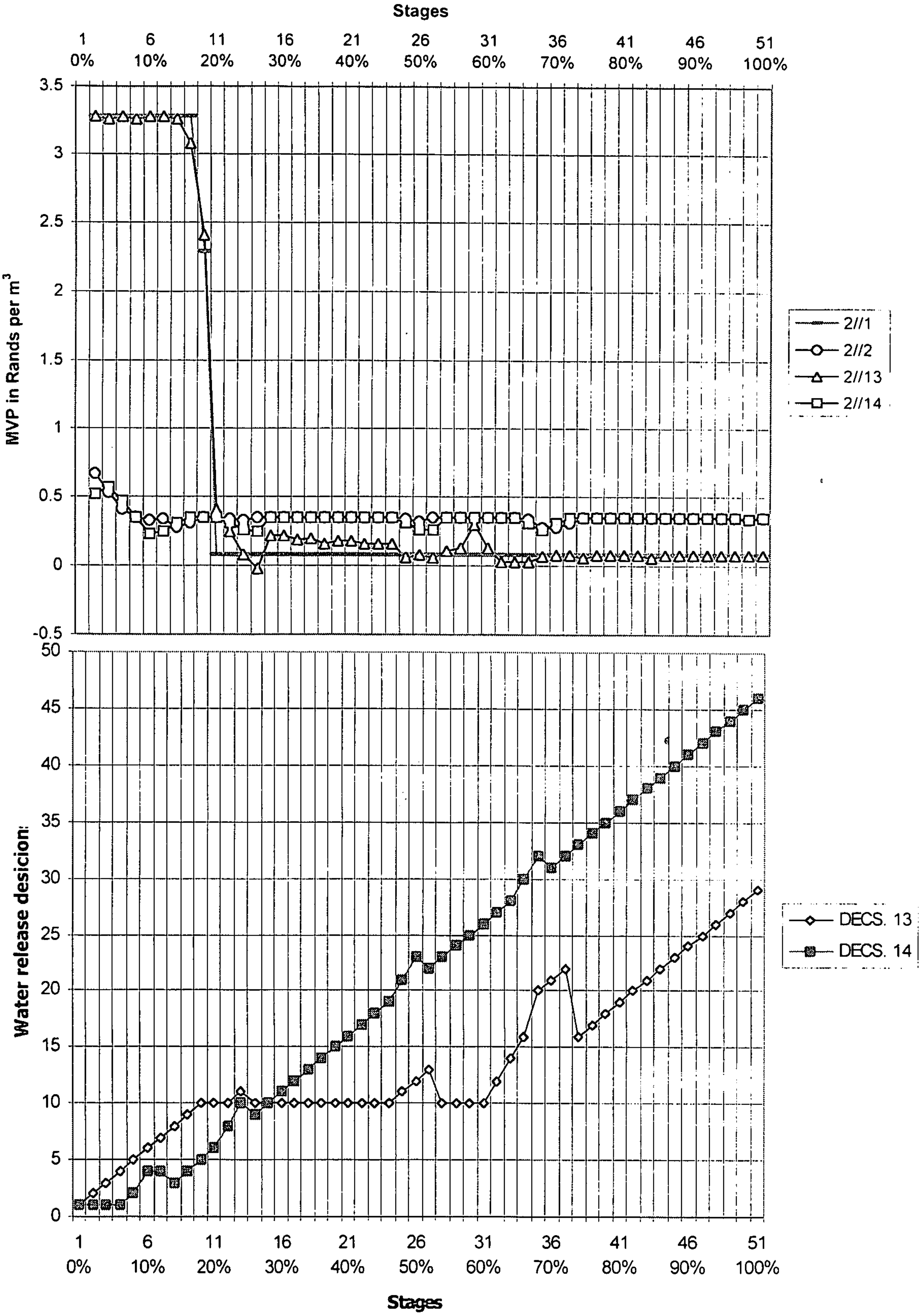


Figure 6.18: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 75% of Base Case (PMW)

Scenario 3 (CS and IS 50% of BC) PMW - Figure 6.19

- Figure 6.19 shows the cut-off point along the horizontal axis to be approximately 284 475 m^3, which is 50 per cent of base case. The horizontal distance between successive points in Figure 6.19 is 5 690 m^3 this represents 2 per cent of 284 475 m^3
- No major changes in summer MVPs are noted compared to the Scenario 2 case.
- Winter MVPs are much higher (i.e. at near-zero CS content) than in the base case and scenario 2 above, confirming the increasing scarcity of water.
- The number of seasons remaining in the farmer's planning horizon has a greater impact on summer MVPs in the maize range than on winter MVPs generally.
- As reservoir CS contents increase from zero, the amount of water saved before any is allocated to winter wheat is increasing as water gets scarcer. In this scenario the saving is about 70 per cent of the quantity required to fully irrigate summer potatoes. Again no summer water saving occurs until reservoir CS contents exceed the maximum potato requirements. Then saving usually occurs when the long-planning horizon MVPs (3//13) are greater than the immediate-season maize MVPs (3//1) but with some quite irregular values.

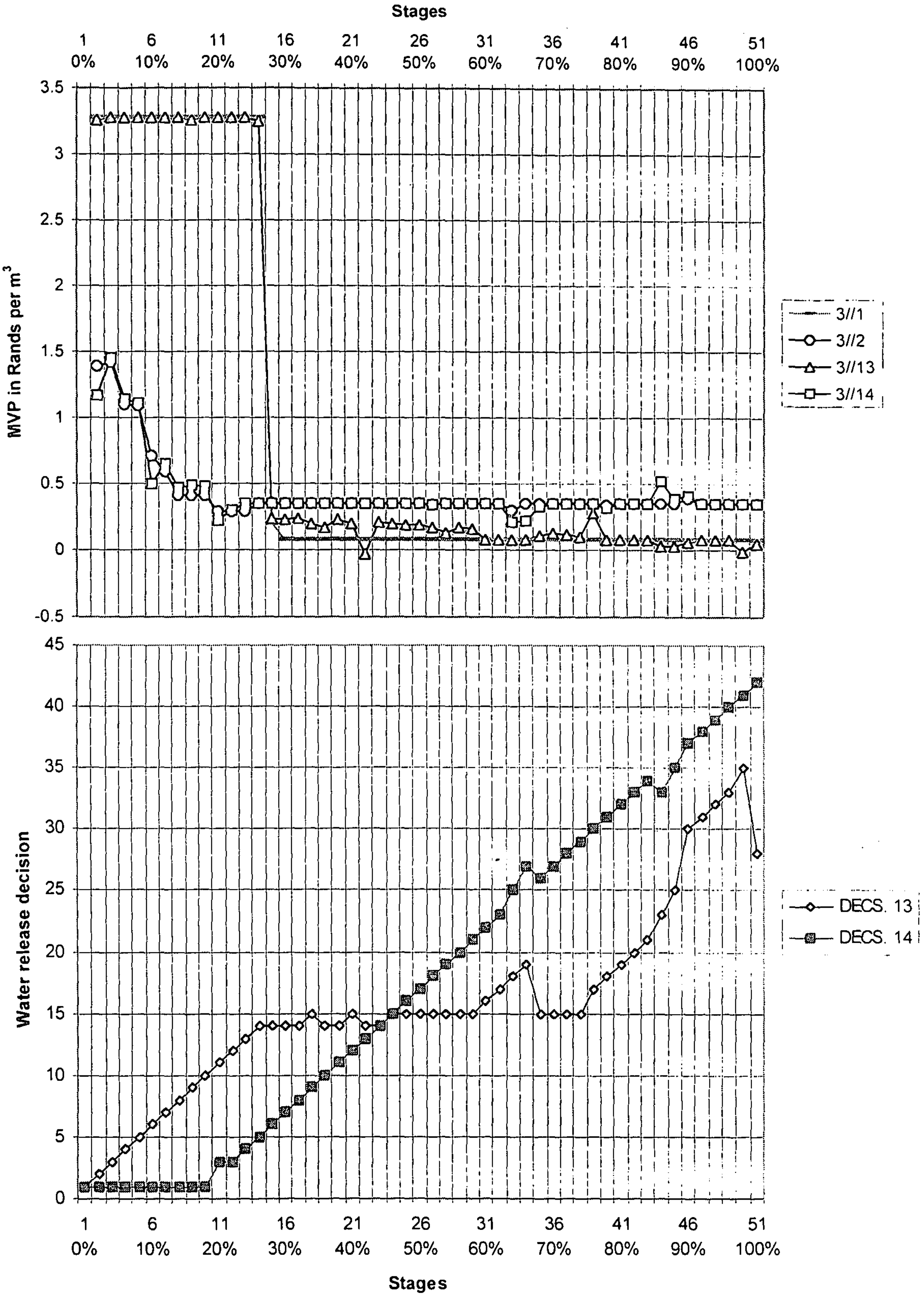


Figure 6.19: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 50% of Base Case (PMW)

Scenario 4 (CS and IS 25% of BC) PMW - Figure 6.20

- In this case the cut-off point along the horizontal axis is approximately 142 238 m^3, which is 25 per cent of base case. The horizontal distance between successive points in Figure 6.20 is 2 845 m^3 representing 2 per cent of 142 238 m^3
- Summer long-planning-horizon MVPs (4//13) show more irregularity than previous scenarios that include potatoes. Winter MVPs show much higher values at near-empty reservoir CS contents than previous scenarios, reflecting the further increased scarcity.
- Winter water saving (lower section of Figure 6.20) is most pronounced here. It is approaching 80 per cent of that required to fully irrigate summer potato. Once more, summer water saving does not occur until the potato crop is adequately provided for. The long-planning-horizon MVPs (4//13) in Figure 6.20, generally exceeding the maize MVPs (4//1), indicates that such saving is for the next-season wheat or perhaps even potatoes in the following season. However, the quantity saved before allocating extra reservoir CS water to maize is less than in Scenarios 1, 2 or 3. Nevertheless, because of the increased scarcity, maize is receiving a greater percentage of a full reservoir CS contents not allocated to potatoes than in the previous scenarios.

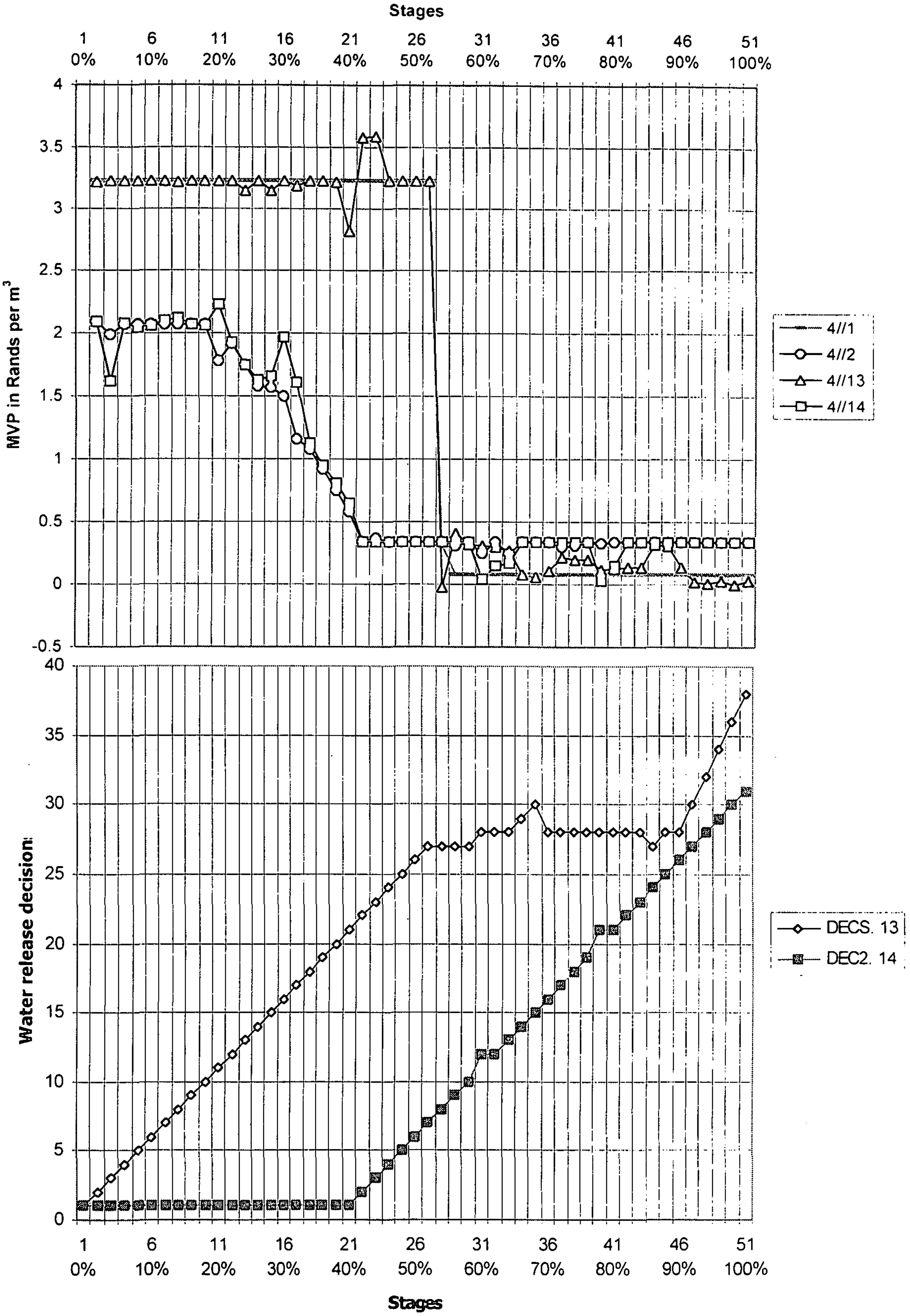


Figure 6.20: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 25% of Base Case (PMW)

Scenario 5 (CS same as BC but IS doubles) PMW - Figure 6.21

- The number of seasons remaining in the farmer's planning horizon has little impact on the MVPs (Figure 6.21).
- MVPs in this scenario, generally assume base case characteristics.
- No summer water saving is noted as shown in the lower section of Figure 6.21. The higher inflows mean that no water saving is desirable, regardless of reservoir contents.
- Winter water saving only started when CS content is about 400 000 m^3 after the season's requirements to maximize wheat production are met, as in base case.

Scenario 6 (CS same as BC but IS halves) PMW - Figure 6.22

- Winter MVPs are much higher (i.e. at near zero) than in base case confirming the increased scarcity of water resulting from lesser inflows and these higher MVPs reflect the value of water saved to reduce the likelihood of lack of water for the highly profitable potatoes in the following summer.

- The number of seasons remaining in the farmer's planning horizon has a significant impact on the summer MVPs. With 13 seasons to go, (6//13) MVPs are on the average higher than the case of one season left (6//1).
- Reduction in inflow shares spell increased water scarcity. No water is allocated to wheat in the immediate season until reservoir CS contents exceed 10 per cent (56 895 m^3) of capacity. Savings then remain almost constant until the wheat requirements are met.
- Pronounced water saving in summer is indicated after the requirement of the maximum potato is fully met. This saving continues almost continuously until reservoir CS contents equal 80 per cent of capacity (455 160 m^3). Only then is some water to be allocated to maize in the immediate summer.'

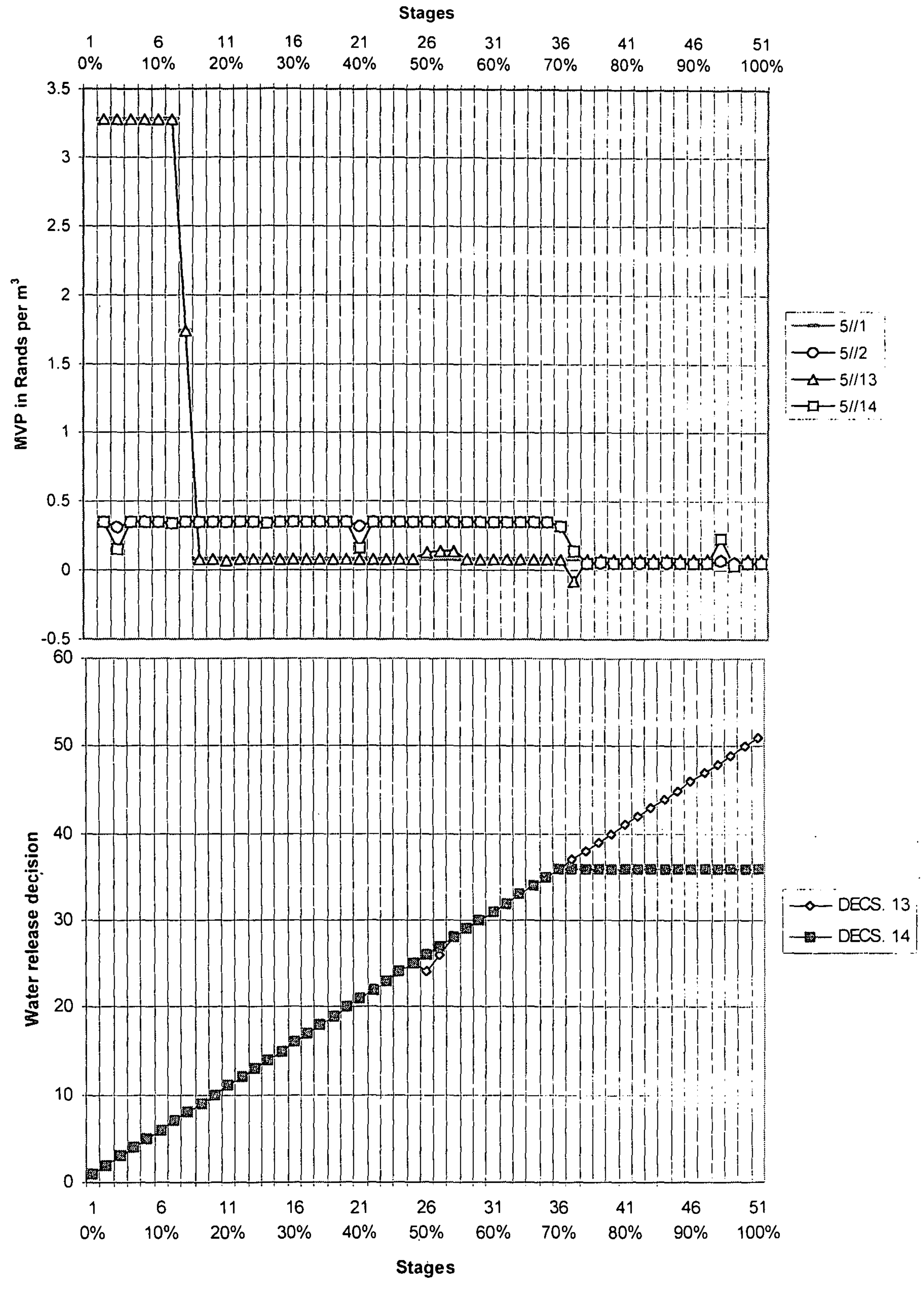


Figure 6.21: MVP in Rand per m^3 and optimal water release decisions when CS equals Base Case and IS is 200% of Base Case (PMW)

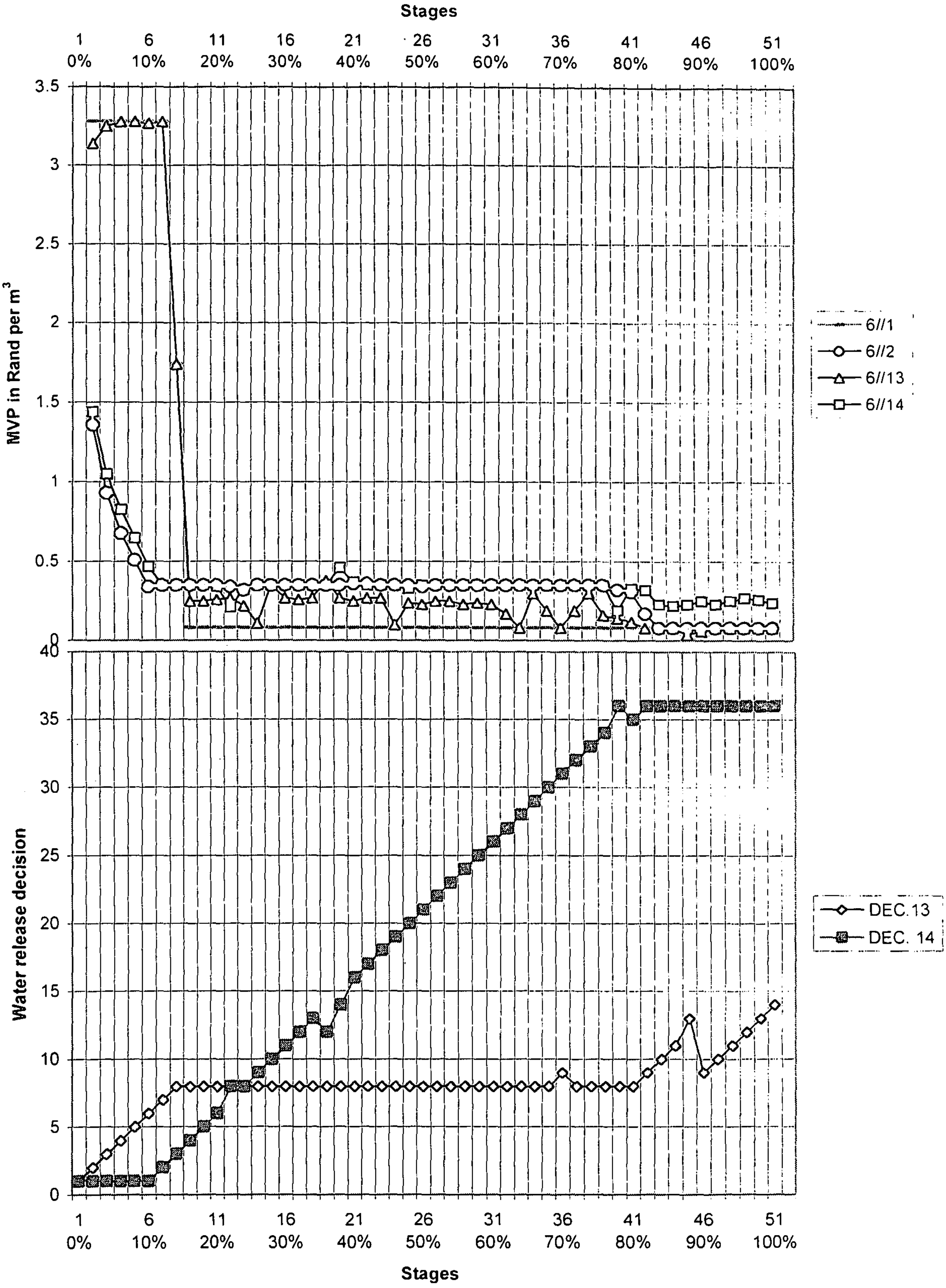


Figure 6.22: MVP in Rand per m^3 and optimal water release decisions when CS equals Base Case and IS is 50% of Base Case (PMW)

Scenario 7 (IS same as BC but CS halves) PMW - Figure 6.23

- In this case the cut-off point along the horizontal axis is 284 475 m^3 as in scenario 3
- The number of seasons remaining in the farmer's planning horizon has only minor impact on the MVPs.
- MVPs reflect the halving of the CS capacity similar to those of scenario 5.The lower section of Figure 6.23 shows that, in winter, the first 8 per cent of the now-reduced reservoir CS capacity is saved before CS contents are allocated to wheat. As reservoir CS contents increase further, winter saving remains more or less constant, with deviations corresponding to irregularities in the long-planning-horizon MVPs (7//14) in the upper portion of Figure 6.23. As in other scenarios above, increases in summer reservoir CS contents are allocated to potatoes until the long-planning-horizon MVPs (7//13) fall to the maize level. Then 10 per cent of the reservoir capacity is saved until increasing reservoir CS contents are allocated to maize. The quantity saved remains constant until reservoir CS contents reach about 60 per cent of capacity, but then reduces irregularly until a full reservoir CS is all allocated to the immediate summer crops.

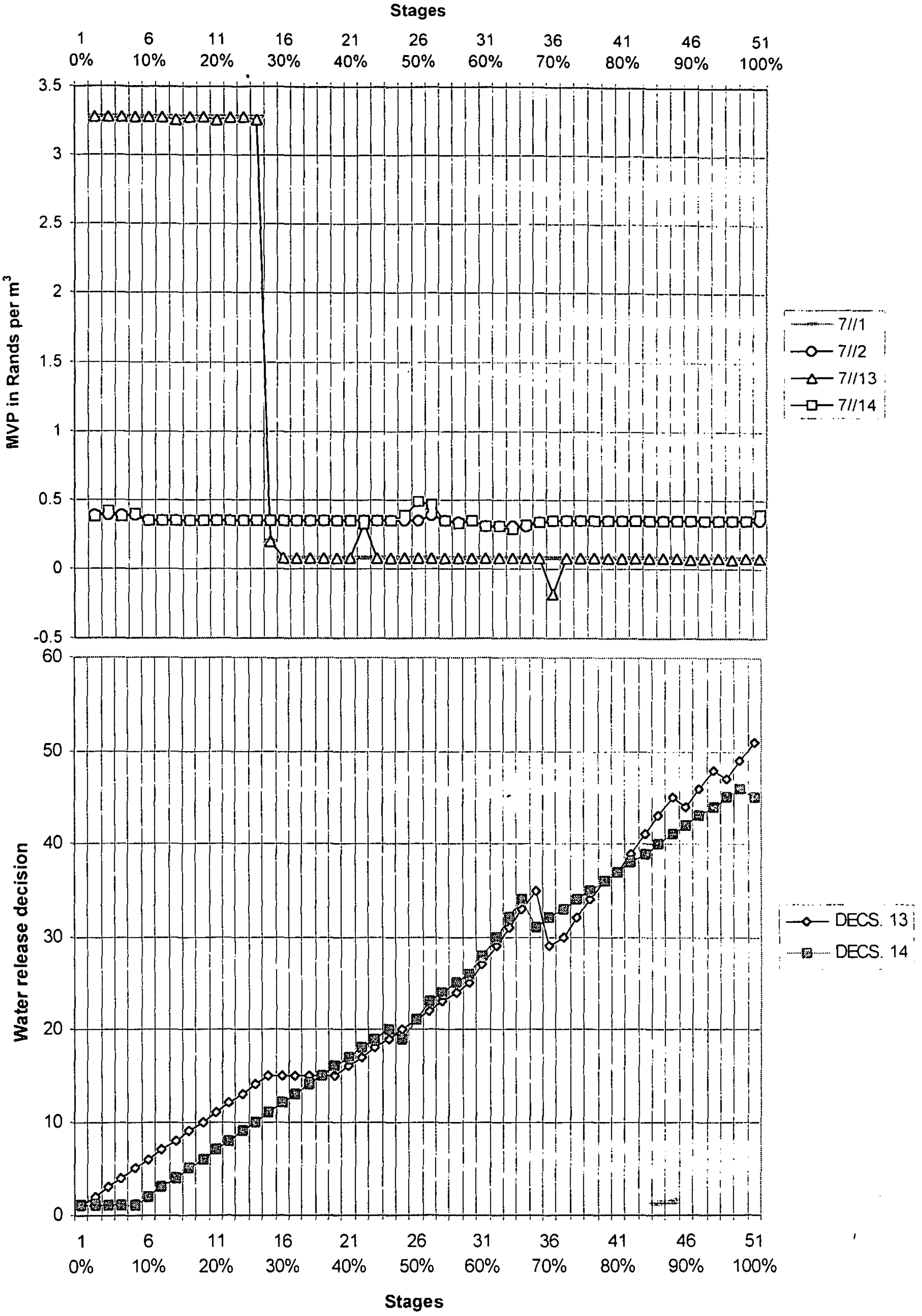


Figure 6.23: MVP in Rand per m^3 and optimal water release decisions when IS equals Base Case but CS halves (PMW)

Scenario 8 (CS and IS double BC) PMW - Figure 6.24

- Again MVPs are similar to that of base case, when CS contents are within current season's requirements
- Beyond season's requirements, very low MVPs in the vicinity of R 0,05 per m^3 and below are recorded irrespective of the season or the number of seasons left in the planning horizon.
- From about 1 200 000 m^3 CS content, MVPs become completely zero as the maximum quantity of water farmer can use profitably in the immediate and future seasons is exceeded
- With water relatively abundant, no water savings occurred in winter (Figure 6.24) until the season's requirements are fully met. Beyond full reservoir CS content non-economic water release decisions reflecting spills are evident in both winter and summer.

Scenario 9 (CS and IS triple BC) Figures 6.25 and Scenario 10 (CS and IS quadruple BC) Figures 6.26 PMW

Scenarios 9 (CS and IS triple BC Figure 6.25) and 10 (CS and IS quadruple BC Figure 6.26) follow the same explanation as in scenario 8 Figure 6.24 above.

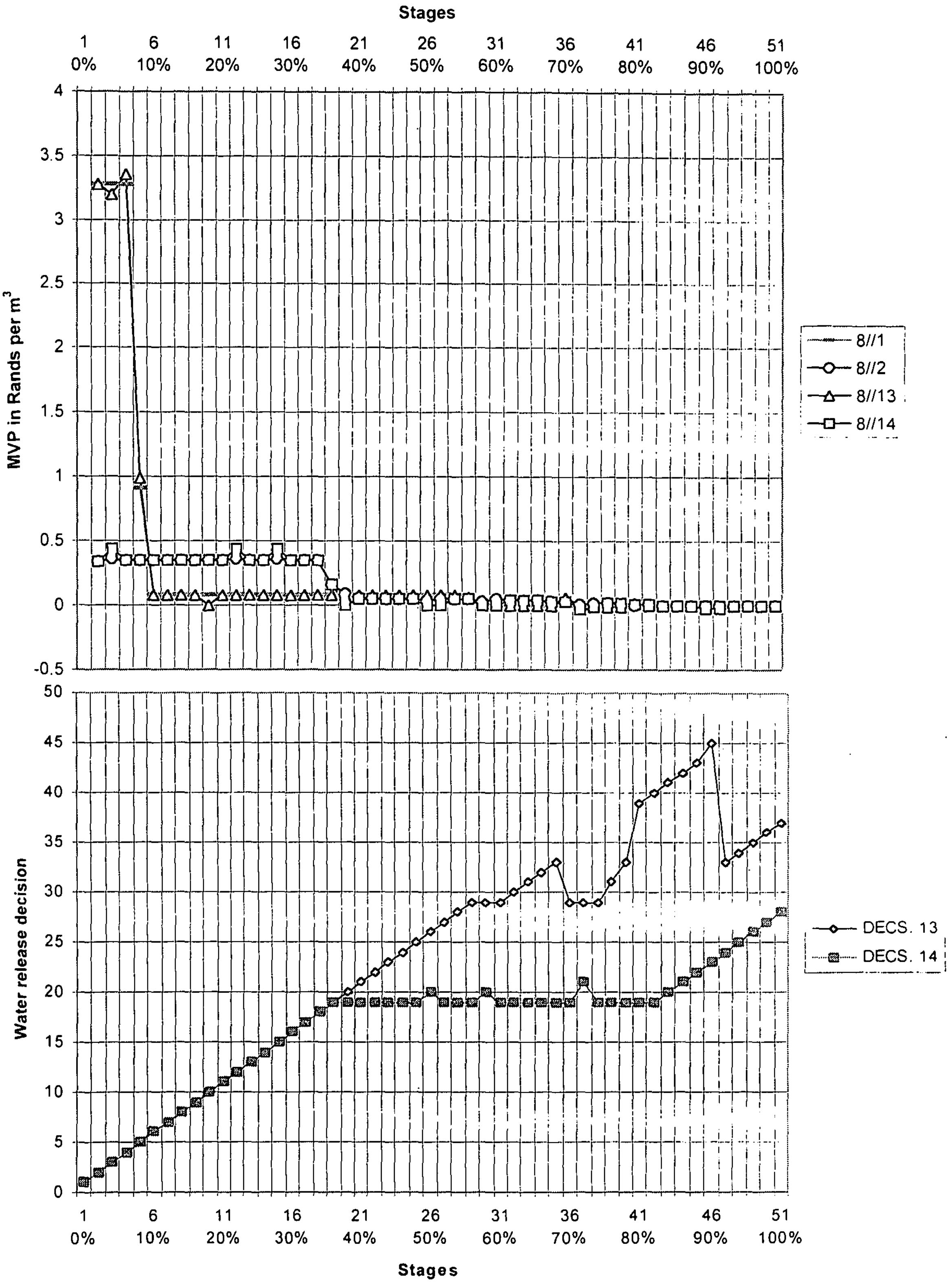


Figure 6.24: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 200% of Base Case (PMW)

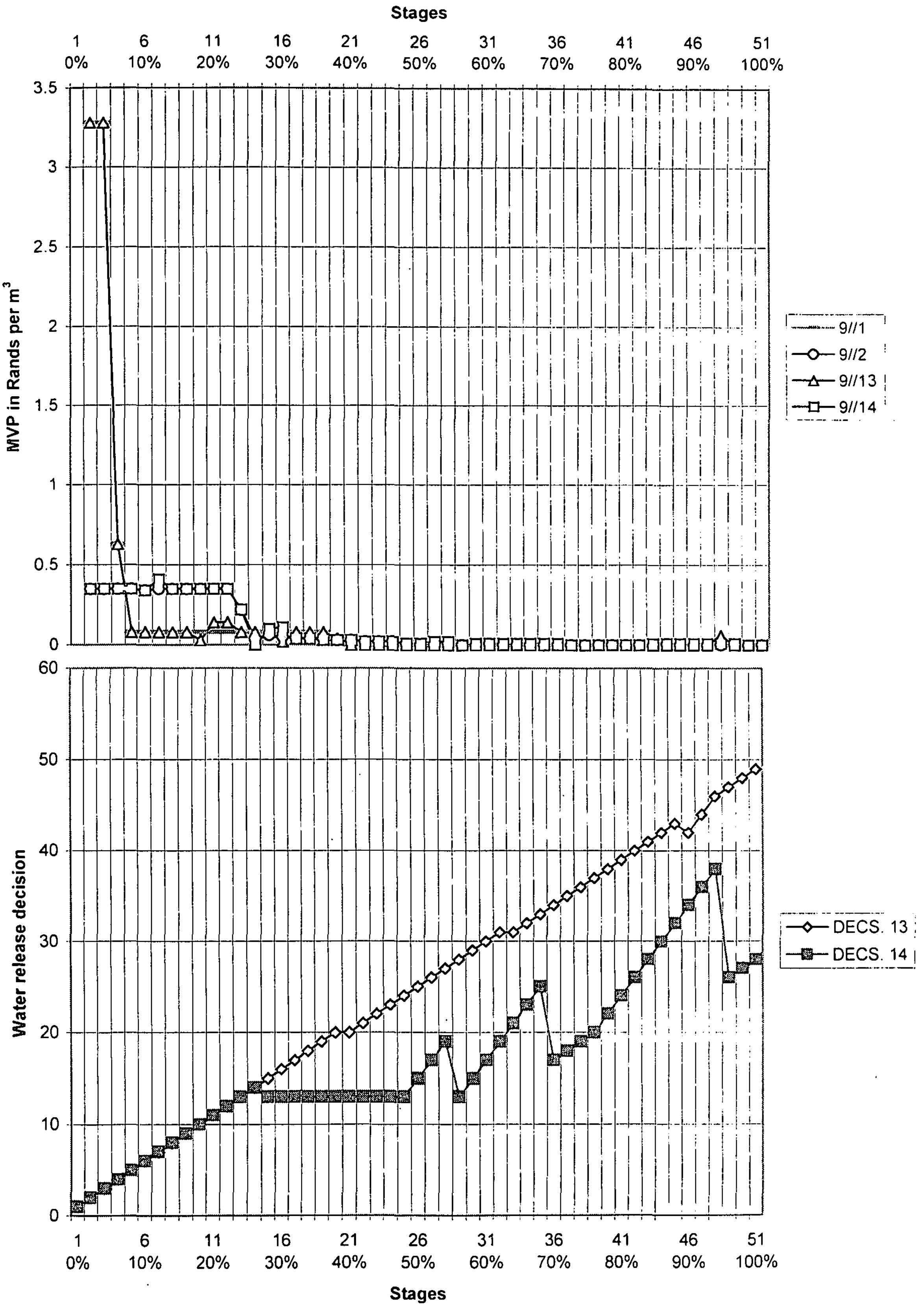


Figure 6.25: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 300% of Base Case (PMW)

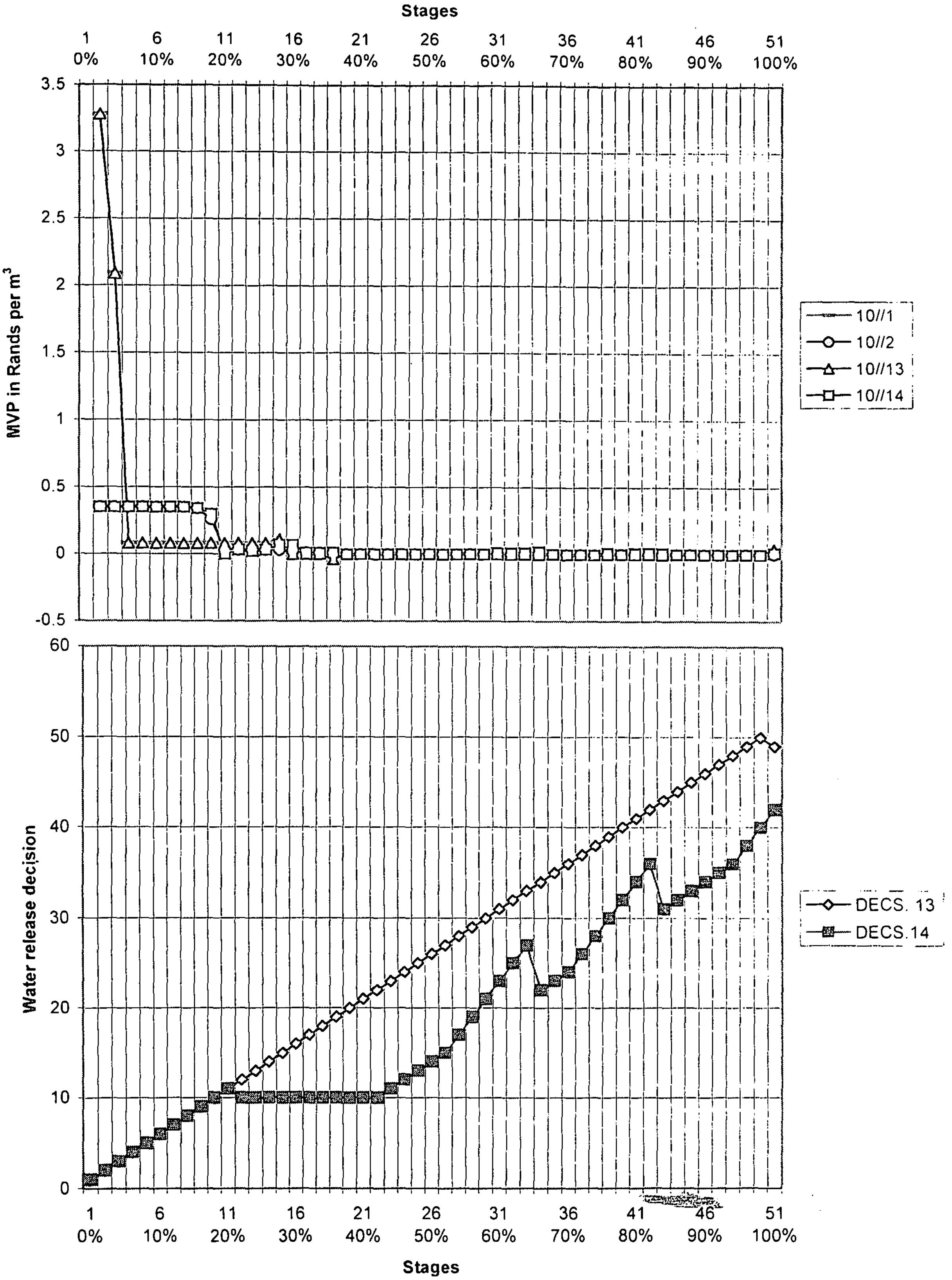


Figure 6.26: MVP in Rand per m^3 and optimal water release decisions when both CS and IS are 400% of Base Case (PMW)

6.4 THE IMPACT OF USING SDP RELEASE RULES

TABLE 6.11: The average seasonal CS inflows and the beginning of season CS contents

RUN NUMBER	RES.CS SHARE 10^3 m^3	RES. CS INFLOWS 10^3 m^3	CS INFLOWS DURING SEASON 10^3 m^3		START OF SEASON CS CONTENTS			
					USING SDP RULES 10^3 m^3		AS AVAILABLE 10^3 m^3	
			Mean w	**Mean** s	**Mean** w	**Mean** s	**Mean** w	**Mean** s
1	1.00	1=727.2	301.68	727.2	575.08	437.81	541.37	291.09
2	0.75	0.75	226.26	545.4	436.14	275.13	403.34	217.46
3	0.50	0.05	150.84	363.6	312.87	144.2	256.32	143.84
4	0.25	0.25	75.42	181.8	153.74	70.34	127.29	70.21
5	1.00	2.00	603.37	1454.41	703.61	632.24	704.64	459.69
6	1.00	0.50	150.84	363.6	473.78	263.28	342.61	143.19
7	0.50	1.00	211.97	546.59	350.93	228.86	350.79	228.75
8	2.00	2.00	603.37	1454.41	1226.97	1158.54	1093.47	585.61
9	3.00	3.00	905.05	2181.61	1687.34	1505.79	1645.58	880.11
10	4.00	4.00	1206.74	2908.81	2196.54	1756.21	2197.69	1174.62

Table 6.11 shows the mean CS inflows that the farmer experiences when he is entitled to given reservoir capacity shares. These reservoir capacity shares and CS inflows are calculated at the beginning of each season, using SDP rules on one hand and no rules (meaning just as water is available) on the other.

In the first row the 75 ha LMW farmer with a reservoir CS size of 727 200 m^3 will experience mean inflows of 301 680 m^3 and 727 200 m^3 for winter and summer respectively. With the available hydrology data, the farmer using SDP rules would have a mean CS content of 575 080 m^3 at the beginning of winter season and 473 810 m^3 at the beginning of summer. On the contrary, if a farmer uses water just as it becomes available, the mean starting CS contents will be 541 370 m^3 and 291 090 m^3 for winter and summer respectively. Vertically down the table other situations of reservoir CS shares are considered and the corresponding inflows as well as the CS contents recorded.

Table 6.12: Seasonal and Annual Mean Gross Margins using SDP and non-SDP rules (000s of Rands).

RUN NUMBER	RES. CS SHARE	RES.CS INFLOWS	USING SDP-DERIVED POLICIES				USING RES.WATER AS AVAILABLE			
			Mean w	Mean s	Mean Annual	S.D.	Mean w	Mean s	Mean Annual	S.D.
1	1=727.2	1.00	131.61	49.50	181.1	26.85	131.38	38.93	170.3	28.03
2	0.75	0.75	126.48	31.68	158.16	31.65	120.20	30.96	151.16	33.93
3	0.50	0.50	108.78	10.49	119.27	29.61	92.47	22.27	114.74	39.91
4	0.25	0.25	53.46	4.43	57.89	16.01	44.36	11.46	55.82	20.12
5	1.00	2.00	138.48	71.86	210.34	8.81	138.48	56.44	194.92	20.85
6	1.00	0.50	122.53	12.08	134.61	34.92	95.37	22.19	117.57	40.85
7	0.50	1.00	122.27	33.84	156.11	18.17	122.26	33.91	156.17	18.09
8	2.00	2.00	138.48	82.63	221.11	8.37	138.48	58.49	196.97	23.61
9	3.00	3.00	138.48	86.30	224.78	0	138.48	67.21	205.69	20.05
10	4.00	4.00	138.48	86.30	224.78	0	138.48	73.96	212.44	17.36

Table 6.12 looks at two factors namely, reservoir capacity share and inflows (both of which determine a farmer's water supply reliability) and the effect these factors have on seasonal as well as annual gross margins.

For each pair of reservoir CS and inflows seasonal and annual GMs are determined using SDP derived policies on one hand and on the other hand using reservoir water just as it becomes available. That is, there is no deliberate water saving in one season to increase the likely availability in subsequent seasons. The two factors are then varied to simulate different water scarcity scenarios and the effects of these on GMs.

For example, in the first row where the farmer has a CS of 727 200 m^3 and entitled to his base case inflow share:

- Using SDP-derived policies obtained from SIM-DY-SIM, the 75 ha PMW farmer will receive a mean winter GM of R 131 610 and R 49 500 for summer, summing up to a mean annual GM of R 181 110 with a standard deviation of R 26 850.
- Comparatively, using reservoir water as it becomes available gives the same farmer R 131 380 and R 38 930 for mean winter and summer GMs respectively.

This gives a mean annual gross margin of R 170 300 and a standard deviation of R 28 030.

The table confirms that the annual gross margin is higher using SDP-derived policies as against using reservoir water as it becomes available. This result justifies the use of the SDP model to aid farmers to make optimal decisions pertaining to water use and hence maximising their revenue.

6.5 IMPLICATIONS FOR WATER MANAGEMENT

The above results focus discussions on the implications for water resource management, the value of water as well as water trading.

6.5.1 Water resource management

The basic principles of CS is that 'water resources' be considered as a share of the capacity of a reservoir, and a percentage or proportional share of the inflows into, and evaporation and seepage losses from, the reservoir or dam, are to be allocated to users on a sufficiently long-term basis that water users will have the incentive to efficiently use all resources under their control. Hence medium to long-term rights to a portion of reservoir capacity and to a proportion of reservoir inflows and losses necessarily must be allocated and priced.

With the appropriate institutional arrangements (non-attenuated rights) in place, farmers will be entitled to future water in proportion to the total inflows received. The user then has incentives to use those rights efficiently, so long as the allocation is large enough and the price low enough for the user's operations to be economically viable and those rights protected by law.

This form of property rights system will promote efficiency in water use, which will support overall sustainable use of the resource. As a result, water for the agricultural sector now and in the future as per this study (methodology) can be better managed through the appropriate management of inflows (inflow shares) and reservoir space (capacity shares). Undoubtedly, this will reduce misuse of water resources and consequently freeing water for re-allocation to other sectors to achieve a more equitable allocation.

This allocation mechanism is perceived to be transparent and much more flexible than rigorous quota systems which sometimes promote misallocation, inefficient use (waste) and are difficult to adjust. It also has a great potential to contribute to resolving the daunting task of achieving equitable water allocation between different sectors. However, the duty of achieving equity will be controlled by the relative shares of both storage space and inflows, allocated and priced (or priced and allocated in a market) across the various users, uses and sectors.

In a nutshell, the study demonstrates how CS can be used to enhance efficiency in water management through non-attenuated user rights to shares of storage space and proportional inflows. In addition the study reveals how farmers can allocate or manage resources freely to the best of their ability given non-attenuated rights to water use.

6.5.2 Water value

The marginal value products derived in this study are linked to;

- The cropping enterprise in question; and
- Water scarcity (seasonal fluctuations)

It is deduced from the study that crops with comparatively higher GMs resulted in higher marginal value products. Also as water becomes scarce MVPs increase accordingly. Since these MVPs determine the farmer's ability to pay for water now or in the future, the incentive to use water judiciously will be governed by these values. That means how much water to use in the short-run, or conserved for medium and long-term use are linked to these values. The implications for efficient water management and hence sustainable water use become apparent.

6.5.3 Water trading

The results of the SDP model will provide the farmer with adequate information to manage his share of water allocation efficiently without any external interference. The farmer, by knowing what his reservoir contents will be at the beginning of a season will be able to determine whether his water requirements for the next season will be adequately met or in excess. Whatever the situation, farmer can either

- Buy water from a willing seller who for one reason or the other may not want to utilise all his water during a season; or
- In the event of excesses offer to sell ahead of inflows to avert possible spills.

Under this system therefore water trading will become very necessary to facilitate free flow of water resources either within a sector (say between farmers) or between sectors. The implications are that the appropriate institutional provisions that will guarantee exclusive user rights, which are transferable through trade and enforced by law, have to be made to allow the farmer to manage water as she/he deems fit.

6.6 CONCLUSION

The SIM – DY – SIM model used in this study successfully provides useful information on users' content of reservoir capacity shares regarding:

- How much water to allocate for the immediate season;
- How much water to carry to the next season;
- The start of season's reservoir content (the factor that indicates user's water supply reliability)

These are vital water scarcity indicators that will certainly assist in determining the true scarcity values of water. The general information on the farmer's water use and reservoir contents will also facilitate a better water allocation.

The marginal value products (MVPs) determined from LP for the immediate season's decision-making and from SDP for intermediate/long-term decision-making:

- determine the farmer's ability to pay for the resource;

- provide good guidance to farmer on how water should be valued and hence used or saved for use in the immediate season or the future.

The above information is valuable for water managers as well, in the sense that they are empowered on how to really value water.

The most efficient use of scarce resources is the major concern of economists. This case study provides some insight into how a farmer can optimise (maximise) his gross margin and for that matter revenue with a given resource. The case in point in the study is; using SDP derived policies, which were obtained from SIM-DY-SIM to determine the farmer's mean seasonal gross margin and comparing it with the mean gross margin obtained without using the SDP derived policies. Results indicate that, using SDP derived policies optimises both water use and gross margins.

Medium to long-term rights to a portion of reservoir capacity and to a proportion of reservoir inflows and losses necessarily must be allocated on a sufficiently long-term basis so that, water users will have the incentive to efficiently use all resources under their control. These rights must also be priced low enough for the user's operations to be economically viable.

CHAPTER 7

SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 INTRODUCTION

This study mainly focused on evaluating Capacity Sharing as an alternative institutional arrangement for water management and it's applicability to South Africa. A summary of the achievements that were realised through specified objectives as well as the conclusions and recommendations are presented below.

7.2 SUMMARY OF FINDINGS

The findings of this study are summarised under three headings: South Africa's water institutional arrangements; evaluation of Capacity Sharing as an alternative water institutional arrangement for South Africa; and the marginal value of irrigation water at the Vanderkloof Dam.

7.2.1 SOUTH AFRICA'S WATER INSTITUTIONAL ARRANGEMENTS.

The first objective was to evaluate institutions and legislation to determine whether the appropriate institutional provisions are in place for effective water resource management in South Africa.

In Chapter 3 this objective was realised by first looking at the theory and principles of institutional arrangements. An ideal water institutional framework for achieving water security was then developed. This was followed by a summary of the evolution of water related institutional arrangements in selected countries internationally in order to disclose global trends. Using the developed ideal institutional framework and global trends and patterns in water policy and institutional arrangements, the South African water laws and water policy was evaluated.

The evaluation of institutional arrangements for water management in South Africa revealed that, a great deal of progress has been made towards effective, efficient and sustainable water management.

The new National Water Act (NWA) of South Africa drew international attention on its position regarding identifying and making efforts to address issues like:

- guaranteeing access to sufficient water for basic needs of all people;
- ensuring that the requirements of the environment are met relative to other uses;
- sustainability and renewability of water resources;
- provisions for the transfer of water between catchments;
- honouring obligations to its neighbours; and
- fulfilment of commitment as custodian of the nation's water resources.

But to steer water management thinking more along current international trends which stipulates the following:

- safeguarding water quality;
- shifting from development of new sources of water to allocating water more efficiently;
- adopting an integrated approach to water management;
- placing a premium on economic viability and physical sustainability;
- using economic instruments to manage water; and
- promoting stakeholder participation,

minor adjustments of the NWA may be necessary for a more efficient water resource management.

In summary, the under-mentioned factors besides deviating from current international water institutional trends, seriously fall short of the ideal institutional arrangement that will lead to water security and therefore need urgent attention:

- excessive central government control of water management institutions;

- bureaucratic consented water re-allocations;
- administratively set pricing mechanisms;
- lack of appropriate arrangements to facilitate tradable entitlements (e.g. defining exclusive rights to entitlements);
- discouraging and unclear water transfer arrangements; and
- lack of definitive institutional provisions for integrated demand and supply management.

7.2.2 EVALUATION OF CAPACITY SHARING AS AN ALTERNATIVE WATER INSTITUTIONAL ARRANGEMENT

The second objective of evaluating Capacity Sharing as an alternative institutional arrangement was executed in Chapter 4. The constitution and features of CS were first highlighted. The advantages and disadvantages, the benefits that South Africa can derive from this unique institutional arrangement as well as how CS will be applied in South Africa were exposed. Finally, CS was evaluated within the framework of the NWA to determine its compatibility.

From this evaluation it is evident that CS will serve the needs of South Africa well because of its dependence on water markets, which have strengths regarding security of tenure, predictability, flexibility, opportunity cost pricing and efficiency of water use. The study of diverse institutional arrangements for water management also revealed that Capacity Sharing has more advantages compared with the other institutional arrangements like Priority Sharing, Discretionary and Consensus Allocation which are more centralised.

Using CS, CMAs will enjoy a lot of credibility because at bulk allocation level, there is transparency since CS is precise, concise and a clear mechanism for allocating water through time even under conditions of uncertainty. CS can equally accommodate water banking that is proposed for addressing the pressing and crucial issue of social equity.

However, CS specifies that water rights be non-attenuated in order to guarantee security of tenure. This condition is compatible with international trends and ideal institutional arrangements regarding property rights. The evaluation of South African institutional arrangement for water management reflects some inadequacies in the property right provisions. Prior to licensing water users are requested to register their water use. This registration does not give entitlement or right to use. In addition the short-term (five-year re-evaluation of permits) licensing and the role of government regarding issuing and re-evaluation of permits, falls fairly short of capacity sharing requirements. This in a way is tantamount to attenuation of rights. The 40-year license, however, is long enough to encourage long term investment provided no political interventions take place. It will therefore be more accommodating if autonomous powers are given to CMAs and WUAs to control the licensing process without any external interference. In this case the licensing process is unlikely to be biased especially during compulsory licensing which may be necessary under certain circumstances.

Market trading of entitlement is also seriously restricted as in Sections 26 and 45 of the NWA. The prescribed procedures for allocation of water by public tender or auction with ministerial control is also not compatible with CS.

Water transfer mechanisms are all purely administrative and all arrangements to this effect are also under ministerial control. This excessive power vested in the Minister generally with regard to sales and transfers of water resources does not augur well for the establishment of CS.

Under CS, water markets will determine the prices to be used to achieve efficient re-allocation of water. Any administrative interference will seriously compromise the allocation of resource to its most efficient uses. Sections 56 – 60 of the NWA and certain announcements on pricing strategy in the Department of Water Affairs and Forestry (1999b) document, endorsed administrative approaches to pricing (i.e. All pricing of water are to be done in line with the needs of the national water strategy)_which is highly incompatible with CS.

The above four factors: property rights, water markets, transfers and pricing together as well as the general administrative interference in water management issues do not make the prospects attractive for the adoption of CS in South Africa.

However, the provisions in the NWA for the establishment of CMAs and WUAs and the progress made thus far in this regard opens the door for a more relaxed water management environment where CS is most likely to be considered. CMAs will progressively monitor and measure stream inflows, rainfall into the reservoir and record all losses due to evaporation, seepage and reservoir overflow spills. These records, together with ordered releases by each of the bulk users, will assist CMAs to update shareholdings of users. Computer printouts of these records (water accounts) reflecting user's reservoir capacity will be sent to holders of bulk shares periodically. One other major role CMAs can play under CS in South Africa is protecting the interests of the large group of currently emerging small-scale farmers. This group of farmers may not have the capacity to operate individual retail shares as large commercial farmers. CMAs will therefore have to secure a bulk allocation for this emerging group and delegate WUAs to carry out the administrative, supply-side as well as demand-side management decisions on their behalf, until they attain the required skills to integrate this supply and demand management themselves. WUAs, on the other hand, will operate at retail level with responsibilities similar to those of CMAs, who oversee bulk shares, but in this case a large number of smaller shareholders will exist. Essentially WUAs will:

- administer capacity share accounts;
- electronically distribute account printouts and any relevant information to groups, individuals or group representatives;
- play a vital role when a combination of retail/bulk shares are required to address the needs of the emerging or small scale farmers;
- be responsible for training water users, as this will empower them to operate their shares effectively and efficiently.

Households, firms or any end users under CS will enjoy full benefits of learning to manage their own demand and supply overseen by the WUA. It is important to mention that since all individual users have a say in the WUA administration, no one is likely to be undermined. Equity issues will be addressed and the concerns of emerging and/or small-scale farmers cannot be compromised. Small-scale farmers, being registered members of WUAs, can no longer be marginalised, because under CS, once the right to water use is granted, security of tenure is guaranteed and the concerned water users can only lose or have their use rights challenged when a rule or regulation is flouted deliberately. But the extent of delegation or devolution of powers to these institutions will be very crucial if any progress is expected.

7.2.3 ECONOMIC VALUE OF IRRIGATION WATER AT VANDERKLOOF DAM

The third objective is to determine the short run marginal value of water for farmers served by Vanderkloof Dam. The procedure used to achieve this objective and the results obtained were discussed in sections 6.2.2 and 6.3.1 of Chapter 6. A linear programme was run and the results provided segmented linear functions, which were obtained from the plots of gross margin versus water application. The first derivative of these functions gave the MVP.

The (MVPs) which are short-run seasonal marginal value products (determine the ability of a farmer to pay for water delivered to his/her farm for use in the immediate season). Two crop mix cases were investigated; these are lucern, maize/wheat (LMW) and potato, maize/wheat (PMW).

For the crop mixes investigated, the MVPs differ significantly for the two seasons. For Crop Mix 1 MVPs range between R 0,09 and R 0,39 per m^3, Crop Mix 2 MVPs range between R 0,09 and R 3,64 per m^3 This implies that farmers cultivating LMW and PMW will be able to pay as much as R 0,39 per m^3 and R 3,64 per m^3 respectively for water delivered onto the farm for immediate use.

Objective 4 is to determine inter-seasonal MVPs of water as well as optimal water use policies for farmers along the Ramah Canal at Vanderkloof Dam using the SIM-DY-SIM simulation model. This model was adopted from Australia adjusted to suit South African seasonal conditions (winter and summer).

The SIM-DY-SIM model assumes that, farmers are legally entitled to capacity shares as well as inflow shares. It is very important to note that, in this study four distinguished MVPs and three different markets were identified. The MVPs include;

- LP-derived MVPs, (these have no direct significance regarding capacity sharing) are used to indicate the value of water delivered onto a farm for use in the immediate season as mentioned above.
- The SDP derived MVP, which is the marginal value product of water in the reservoir and is used for inter-season decision making.
- The MVP for long term inflow shares and,
- The MVP for long term capacity shares or empty space in the reservoir.

The last three MVPs are all dependent on the LP derived MVPs.

The three markets mentioned earlier include;

- Market for water already in the reservoir,
- Market for capacity shares and,
- Market for inflow shares.

The third and fourth MVPs mentioned above as well as markets for long term capacity shares and inflow shares are beyond the scope of this thesis, hence only the first-two MVPs and market for water already in the reservoir will be discussed.

To determine these MVPs ten different scenarios (see section 6.3.3) of water availability were investigated, using the same crop mixes LMW and PMW mentioned earlier. In each case, MVPs were derived for thirteen and fourteen seasons to the end of farmer's planning horizon and also for the last two seasons of the planning horizon. The results of LMW and PMW are presented graphically in Figures 6.7 to 6.16 and 6.17 to 6.26

respectively. Each of these figures contain two sections or parts; an upper part, showing the SDP-derived MVPs, and a lower part showing the SDP-derived optimal release decisions from the farmer's reservoir CS. The two-part figures show four MVPs and two decisions. The four MVPs are: MVP from the last season (summer) in the planning horizon, labelled X//1; MVP from the second-last season (winter) in the planning horizon, labelled X//2; MVP from the season (summer) when 13 seasons remain in the planning horizon labelled X//13 and MVP from the winter season when 14 seasons remain, labelled X//14. X refers to the scenario number. The two sets of decisions are optimal water releases for the summer season with 13 seasons remaining in the planning horizon and similarly for the winter season when 14 seasons remain. This is because farmers decision-making regarding how much water to use or save (and for that matter the value attached to water) will be largely determined by the length of the planning horizon.

Empirical results as in sections 6.3.3.1 and 6.3.3.2 show that inter-seasonal MVPs of water for LMW and PMW cover a wide range form R0,09 to R3,64 per m^3 depending on crop mix, farmer's planning horizon and water availability (i.e. inflow shares and capacity share content scenarios).

The results also compared the using of water under SDP derived rules (i.e. based on optimal policies generated from SDP) as against no rules (i.e. using water as it becomes available in the capacity share). Contents of reservoir capacity shares and CS inflows were calculated at the beginning of each season, using SDP rules on one hand and no rules (meaning just as water is available) on the other.

In Section 6.4 a LMW farmer with a reservoir CS size of 727 200 m^3 will experience mean inflows of 301 680 m^3 and 727 200 m^3 for winter and summer respectively. With the available hydrology data, the farmer using SDP rules would have a mean CS content of 575 080 m^3 at the beginning of winter season and 473 810 m^3 at the beginning of summer. On the contrary, if a farmer uses water just as it becomes available, the mean starting CS contents will be 541 370 m^3 and 291 090 m^3 for winter and summer respectively. It was noted that, both reservoir capacity and inflow shares (which are very important factors in determining the farmer's water supply reliability) were better-managed using SDP derived rules than using water with no rules. The differences in the farmer's mean reservoir contents at the beginning of winter and summer using attests to this.

The effect of reservoir capacity share and inflows on seasonal as well as annual gross margins were also investigated. For each pair of reservoir CS and inflows, seasonal and annual GMs were determined using SDP derived policies on one hand and on the other hand using reservoir water just as it becomes available. Varying the two factors different water scarcity scenarios were simulated and the effects of these on GMs determined.

Empirical results show that a 75 ha PMW farmer for example having a CS of 727 200 m^3 and entitled to his base case inflow share:

- Using SDP-derived policies (obtained from SIM-DY-SIM) will receive a mean winter GM of R 131 610 and R 49 500 for summer, summing up to a mean annual GM of R 181 110 with a standard deviation of R 26 850.
- Comparatively, using reservoir water as it becomes available gives the same farmer R 131 380 and R 38 930 for mean winter and summer GMs respectively. This gives a mean annual gross margin of R 170 300 and a standard deviation of R 28 030.

The above values confirm that the annual gross margins are higher using SDP-derived policies as against using reservoir water as it becomes available. This result justifies the use of the SDP model to aid farmers to make optimal decisions pertaining to water use and hence maximising their revenue.

7.3 CONCLUSIONS

International experience continues to indicate that, the use of water right market to allocate water is generally superior to administrative allocations. However, administrative allocations score better in terms of equity, political and public acceptability. In South Africa with equity, efficient and sustainable use of water as the major objectives of the NWA, a blend of well-established water markets subjected to a limited and specific degree of government intervention may be the best institutional option.

From institutional economic viewpoint, welfare implications are crucial regarding optimal as well as efficient allocation and use of resources. Under CS, optimal and efficient allocation of water would be achieved. In addition, the water user enjoys the privilege of managing both supply and demand thereby reducing risk to the barest minimum and hence maximising welfare.

Under the current dam operating procedures, high water releases are made at Vanderkloof Dam during winter (to cater for the high electric power demand), consequently creating space for summer inflows (releases) from Gariep. This procedure gave rise to some negative seasonal inflows that are unacceptable for CS modelling. The effect of this on farmers is not covered in this thesis. It is important to understand that under CS there are no dam operating as such since water user make their own decision.

Capacity sharing therefore has the potential as one of the appropriate alternative institutional arrangements for South Africa and can be used fully or partly to augment the current arrangements. The concept of CS should therefore not be viewed as a complex and unworkable water institutional arrangement. Adequate provisions should therefore be made for its implementation at least at the bulk share level sectorally and at retail level for the agricultural sector in a selected catchment to test its feasibility. However, there is need for minor adjustments regarding:

- defining exclusive rights to entitlement;
- allowing water market to determine prices;
- reducing excessive central government control of water management institutions;
- providing clear water transfer arrangements; and

- institutionally guaranteeing that efficient water users will not lose any part of their permits without adequate compensation). These are pertinent issues if the current institutional arrangement is to accommodate CS.

The shadow prices (MVPs) derived at different water scarcity scenarios and their corresponding optimal water use policies demonstrate the versatility and applicability of the SIM – DY - SIM model in South Africa. The MVPs which, determine the farmer's ability to pay either in the immediate season or in the future, is an asset for determining water prices in both the present and in the future. This information is equally vital for trading water rights.

MVPs also facilitate good water use decision making since reservoir contents with relatively high MVPs result in decisions to release all or most of the contents for use in the immediate season, which implies that, no water is saved. However, when MVPs are relatively low, water saving is recommended. In some cases, the MVPs explain why water has to be saved in one season (say winter) for use in the next season, which means that no water is allocated to winter crop until there is reasonable probabilities that there will be adequate water available at the start of summer season to irrigate the maximum allowable areas of crops to be cultivated. The implications of the above for water transfers and trading and therefore efficient use of water comes to limelight.

7.4 RECOMMENDATIONS

The above conclusions lead to fundamental policy recommendations and also significant issues that will need further research.

7.4.1 POLICY RECOMMENDATIONS

Whenever a system is faced with scarcity, the system has to adjust and become more efficient or face total collapse. As a case in point, the streamlining of water rights and their tradability towards achieving efficiency in the Western United States was a natural response to the relative scarcity of water. It would therefore seem appalling for the perception of water scarcity in South Africa to be used as an argument for the elimination of private water rights and for the increase in Governmental powers.

Deficiencies in the current NWA through this evaluation may lead to inefficiency in water allocation and use and hence aggravate the water scarcity situation in the long run. The following policy recommendations are therefore worth considering.

- The institutional provision for water rights has to be revisited. Water rights need not necessarily be granted in perpetuity, but a considerably long period of time must be guaranteed the user to exercise user rights. In addition, water rights must be more clearly defined, exclusive, transferable and protected by law.

- Although the scarcity value of water is increasing, the political-rooted system of public provisions seemingly insulates the water economy from the influence of actual market forces, possibly due to the weakness of water markets regarding equity. As a suggestion, allocations to address social equity in particular have to be safeguarded by the public sector through market means yet supervised or controlled by CMAs and WUAs. A special institutional arrangement like CS which has the potential to achieve this, has to be given serious consideration as a new institutional arrangement to manage water on sustainable and at the same time addressing social equity.

- The administrative pricing system that takes precedence over pricing via auctions, or water markets needs a further evaluation before it becomes fully institutionalised. Preferably, a market oriented institutional arrangement like CS, which facilitates integrated demand and supply in water management and makes provision for shadow prices (which are good estimates of opportunity cost) to be calculated, has to be thoroughly investigated, streamlined and adopted.

- The strong equity concerns about water markets in South Africa cannot be ignored. Water being vital to life as well as to livelihoods, strong social norms will always argue against it being treated as a simple marketable commodity. For South Africa, the possible negative equity effects on water markets can be mitigated through appropriate policies. From a liberal market viewpoint, one alternative is to use market-based allocations, combined with reduction in the massive capital and operating subsidies on irrigation and water supply, which usually favour better-off producers and urban consumers. This would possibly free-up budgetary resources to target water subsidies to the poorest sectors of the population in both rural and urban areas.

- Inter-sectoral water allocation mechanisms in South Africa at basin and lower levels need to be well developed. Also regional mechanisms like Catchment Management Agencies and Water User Associations have to be autonomous and non-bureaucratically linked to centralised state apparatus in order to promote true decentralisation.

In conclusion, if there is any need for changes to the New Water Act, the most critical change should be the extension and definition of property rights. This will undoubtedly bring about benefits of focused ownership and decentralised decisions. Properly specified water rights are also necessary steps towards water market development. Needless to say that, in the absence of private rights, decisions become separated from incentives; and since there is no reliable way of determining what the most valued uses are, there cannot be any way of ensuring efficiency in both allocation and use.

7.4.2 RECOMMENDATIONS FOR FURTHER RESEARCH

- The establishment and development of water markets in South Africa need to be vigorously pursued. But high transaction costs have been noted as one of the main factors that spell doom for water markets in South Africa and is most likely to impose external costs on the local economy as a result of trading entitlements.

There is need therefore, for further research into causes of high transaction costs and the means of reducing or eliminating them. This may allay the fears of government and consequently promote the legalisation and development of water markets.

- By way of a pilot study, other river basins in South African must be selected for full-scale implementation of Capacity Sharing to really test its applicability, advantages and disadvantages and above all its user friendliness.

- The hydrology data used in the SIM – DY – SIM model simulations assumed a 10 per cent seepage and transmission losses since no information was available. Any water user's water supply reliability depends on accurate and dependable hydrology data. It is advisable therefore, to conduct a proper study on seepage and transmission losses of any canal or river system to which this model will be applied.

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APPENDIX A

Table A1: 180Ha FARM - SUMMER CROP MIX 1.

Water applied (M^3)	Area selected per crop (Ha)			Gross Margin (R)
	Maize	Cotton	Potatoes	
0				0
20,000			4.5	72,876
40000			9	145,753
60000			13.5	218629
80000			18	291506
100000			22.5	364382
120000			27	437258
133500			30	486450
140000		0.75	30	488073
160000		3.7	30	493066
200,000		7.7	30	503,052
240,000		12.4	30	513,038
280,000		17	30	523,024
320,000		21.6	30	533,010
360,000		26.3	30	542,996
392,000		30	30	551,010
400,000	1	30	30	551,725
600,000	25	30	30	569,834
800,000	49	30	30	587,950
1,000,000	73	30	30	606,062
1,200,000	97	30	30	624,175
1,396,500	120	30	30	641,970

Table A2: 180Ha FARM - SUMMER CROP MIX 2

Water applied (M^3)	Area selected per crop (Ha)			Gross Margin (R)
	Maize	Lucerne	Potatoes	
0				0
20,000			4.5	72,876
40000			9	145,753
60000			13.5	218629
80000			18	291506
100000			22.5	364382
120000			27	437258
133500			30	486450
150000		1.1	30	489442
200,000		4	30	498,509
300,000		11	30	516,622
400,000		18	30	534,775
500,000		24	30	552,909
584,000		30	30	568,050
600,000	3	30	30	569,544
800,000	27	30	30	587,657
1,000,000	51	30	30	605,769
1,200,000	74	30	30	623,881
1,400,000	98	30	30	641,994
1,587,900	120	30	30	659,010

Table A3: 180Ha FARM - WINTER CROP

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

Table A4: 240ha FARM - SUMMER CROP MIX 1

Water applied (M^3)	Area selected per crop (Ha)			Gross Margin (R)
	Maize	Cotton	Potatoes	
0				0
20,000			4.5	72,876
40000			9	145,753
60000			13.5	218,629
80000			18	291,506
100000			22.5	364,382
120000			27	437,258
133500			30	486,450
140000		0.75	30	488,073
160000		3.7	30	493,066
200,000		7.7	30	503,052
240,000		12.4	30	513,038
280,000		17	30	523,024
320,000		21.6	30	533,010
360,000		26.3	30	542,996
392,000		30	30	551,010
400,000	1	30	30	551,725
600,000	25	30	30	569,834
800,000	49	30	30	587,950
1,000,000	73	30	30	606,062
1,200,000	97	30	30	624,175
1,400,000	121	30	30	642,284
1,600,000	144	30	30	660,399
1,898,700	180	30	30	687,450

Table A5: 240ha FARM - SUMMER CROP MIX 2

Water applied (M^3)	Area selected per crop (Ha)			Gross Margin (R)
	Maize	Lucerne	Potatoes	
0				0
20,000			4.5	72,876
40000			9	145,753
60000			13.5	218629
80000			18	291506
100000			22.5	364382
120000			27	437258
133500			30	486450
150000		1.1	30	489442
200,000		4	30	498,509
300,000		11	30	516,622
400,000		18	30	534,775
500,000		24	30	552,909
584,000		30	30	568,050
600,000	3	30	30	569,544
800,000	27	30	30	587,657
1,000,000	51	30	30	605,769
1,200,000	74	30	30	623,881
1,400,000	98	30	30	641,994
1,600,000	121	30	30	660,106
2,000,000	169	30	30	696,330
2,090,100	180	30	30	704,490

Table A6: 240ha FARM - WINTER CROP

Wheat

Water applied (M^3)	Area (Ha) Wheat	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

Table A7: Summer objective function matrix

0							DECISION			
0			1	2	3	4	5	6	7	8	9
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	.00	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
1	1	3	.00	2.37	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1	1	4	.00	2.37	4.75	7.12	7.12	7.12	7.12	7.12	7.12
1	1	5	.00	2.37	4.75	7.12	9.49	9.49	9.49	9.49	9.49
1	1	6	.00	2.37	4.75	7.12	9.49	11.87	11.87	11.87	11.87
1	1	7	.00	2.37	4.75	7.12	9.49	11.87	14.24	14.24	14.24
1	1	8	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	16.61
1	1	9	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	10	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	11	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	12	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	13	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	14	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	15	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	16	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	17	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	18	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	19	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	20	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	21	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	22	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	23	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	24	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	25	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	26	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	27	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	28	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	29	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	30	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	31	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	32	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	33	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	34	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	35	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	36	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	37	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	38	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	39	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	40	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	41	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	42	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	43	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	44	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	45	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	46	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	47	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	48	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	49	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	50	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99
1	1	51	.00	2.37	4.75	7.12	9.49	11.87	14.24	16.61	18.99

0			10	11	12	13	14	15	16	17	18
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
1	1	3	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1	1	4	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12
1	1	5	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49
1	1	6	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87
1	1	7	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24
1	1	8	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61
1	1	9	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99
1	1	10	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36
1	1	11	21.36	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73
1	1	12	21.36	23.73	26.10	26.10	26.10	26.10	26.10	26.10	26.10
1	1	13	21.36	23.73	26.10	28.48	28.48	28.48	28.48	28.48	28.48
1	1	14	21.36	23.73	26.10	28.48	30.85	30.85	30.85	30.85	30.85
1	1	15	21.36	23.73	26.10	28.48	30.85	33.22	33.22	33.22	33.22
1	1	16	21.36	23.73	26.10	28.48	30.85	33.22	35.60	35.60	35.60
1	1	17	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	37.97
1	1	18	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	19	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	20	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	21	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	22	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	23	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	24	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	25	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	26	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	27	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	28	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	29	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	30	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	31	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	32	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	33	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	34	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	35	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	36	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	37	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	38	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	39	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	40	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	41	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	42	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	43	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	44	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	45	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	46	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	47	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	48	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	49	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	50	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34
1	1	51	21.36	23.73	26.10	28.48	30.85	33.22	35.60	37.97	40.34

0	19	20	21	22	23	24	25	26	27
S1 S2 S3									
1 1 1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1 1 2	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
1 1 3	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1 1 4	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12
1 1 5	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49
1 1 6	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87
1 1 7	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24
1 1 8	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61
1 1 9	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99
1 1 10	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36
1 1 11	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73
1 1 12	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10
1 1 13	28.48	28.48	28.48	28.48	28.48	28.48	28.48	28.48	28.48
1 1 14	30.85	30.85	30.85	30.85	30.85	30.85	30.85	30.85	30.85
1 1 15	33.22	33.22	33.22	33.22	33.22	33.22	33.22	33.22	33.22
1 1 16	35.60	35.60	35.60	35.60	35.60	35.60	35.60	35.60	35.60
1 1 17	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97
1 1 18	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34
1 1 19	41.76	41.76	41.76	41.76	41.76	41.76	41.76	41.76	41.76
1 1 20	41.76	42.95	42.95	42.95	42.95	42.95	42.95	42.95	42.95
1 1 21	41.76	42.95	44.13	44.13	44.13	44.13	44.13	44.13	44.13
1 1 22	41.76	42.95	44.13	45.32	45.32	45.32	45.32	45.32	45.32
1 1 23	41.76	42.95	44.13	45.32	46.51	46.51	46.51	46.51	46.51
1 1 24	41.76	42.95	44.13	45.32	46.51	47.69	47.69	47.69	47.69
1 1 25	41.76	42.95	44.13	45.32	46.51	47.69	48.88	48.88	48.88
1 1 26	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	50.06
1 1 27	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 28	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 29	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 30	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 31	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 32	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 33	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 34	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 35	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 36	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 37	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 38	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 39	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 40	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 41	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 42	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 43	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 44	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 45	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 46	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 47	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 48	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 49	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 50	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25
1 1 51	41.76	42.95	44.13	45.32	46.51	47.69	48.88	50.06	51.25

0			28	29	30	31	32	33	34	35	36
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
1	1	3	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1	1	4	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12
1	1	5	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49
1	1	6	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87
1	1	7	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24
1	1	8	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61
1	1	9	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99
1	1	10	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36
1	1	11	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73
1	1	12	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10
1	1	13	28.48	28.48	28.48	28.48	28.48	28.48	28.48	28.48	28.48
1	1	14	30.85	30.85	30.85	30.85	30.85	30.85	30.85	30.85	30.85
1	1	15	33.22	33.22	33.22	33.22	33.22	33.22	33.22	33.22	33.22
1	1	16	35.60	35.60	35.60	35.60	35.60	35.60	35.60	35.60	35.60
1	1	17	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97
1	1	18	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34
1	1	19	41.76	41.76	41.76	41.76	41.76	41.76	41.76	41.76	41.76
1	1	20	42.95	42.95	42.95	42.95	42.95	42.95	42.95	42.95	42.95
1	1	21	44.13	44.13	44.13	44.13	44.13	44.13	44.13	44.13	44.13
1	1	22	45.32	45.32	45.32	45.32	45.32	45.32	45.32	45.32	45.32
1	1	23	46.51	46.51	46.51	46.51	46.51	46.51	46.51	46.51	46.51
1	1	24	47.69	47.69	47.69	47.69	47.69	47.69	47.69	47.69	47.69
1	1	25	48.88	48.88	48.88	48.88	48.88	48.88	48.88	48.88	48.88
1	1	26	50.06	50.06	50.06	50.06	50.06	50.06	50.06	50.06	50.06
1	1	27	51.25	51.25	51.25	51.25	51.25	51.25	51.25	51.25	51.25
1	1	28	52.43	52.43	52.43	52.43	52.43	52.43	52.43	52.43	52.43
1	1	29	52.43	53.62	53.62	53.62	53.62	53.62	53.62	53.62	53.62
1	1	30	52.43	53.62	54.81	54.81	54.81	54.81	54.81	54.81	54.81
1	1	31	52.43	53.62	54.81	55.99	55.99	55.99	55.99	55.99	55.99
1	1	32	52.43	53.62	54.81	55.99	57.18	57.18	57.18	57.18	57.18
1	1	33	52.43	53.62	54.81	55.99	57.18	58.36	58.36	58.36	58.36
1	1	34	52.43	53.62	54.81	55.99	57.18	58.36	59.55	59.55	59.55
1	1	35	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	60.74
1	1	36	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	37	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	38	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	39	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	40	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	41	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	42	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	43	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	44	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	45	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	46	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	47	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	48	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	49	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	50	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92
1	1	51	52.43	53.62	54.81	55.99	57.18	58.36	59.55	60.74	61.92

0			37	38	39	40	41	42	43	44	45
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
1	1	3	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
1	1	4	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12
1	1	5	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49
1	1	6	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87	11.87
1	1	7	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24	14.24
1	1	8	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61	16.61
1	1	9	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99
1	1	10	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36
1	1	11	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73
1	1	12	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10
1	1	13	28.48	28.48	28.48	28.48	28.48	28.48	28.48	28.48	28.48
1	1	14	30.85	30.85	30.85	30.85	30.85	30.85	30.85	30.85	30.85
1	1	15	33.22	33.22	33.22	33.22	33.22	33.22	33.22	33.22	33.22
1	1	16	35.60	35.60	35.60	35.60	35.60	35.60	35.60	35.60	35.60
1	1	17	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97
1	1	18	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34
1	1	19	41.76	41.76	41.76	41.76	41.76	41.76	41.76	41.76	41.76
1	1	20	42.95	42.95	42.95	42.95	42.95	42.95	42.95	42.95	42.95
1	1	21	44.13	44.13	44.13	44.13	44.13	44.13	44.13	44.13	44.13
1	1	22	45.32	45.32	45.32	45.32	45.32	45.32	45.32	45.32	45.32
1	1	23	46.51	46.51	46.51	46.51	46.51	46.51	46.51	46.51	46.51
1	1	24	47.69	47.69	47.69	47.69	47.69	47.69	47.69	47.69	47.69
1	1	25	48.88	48.88	48.88	48.88	48.88	48.88	48.88	48.88	48.88
1	1	26	50.06	50.06	50.06	50.06	50.06	50.06	50.06	50.06	50.06
1	1	27	51.25	51.25	51.25	51.25	51.25	51.25	51.25	51.25	51.25
1	1	28	52.43	52.43	52.43	52.43	52.43	52.43	52.43	52.43	52.43
1	1	29	53.62	53.62	53.62	53.62	53.62	53.62	53.62	53.62	53.62
1	1	30	54.81	54.81	54.81	54.81	54.81	54.81	54.81	54.81	54.81
1	1	31	55.99	55.99	55.99	55.99	55.99	55.99	55.99	55.99	55.99
1	1	32	57.18	57.18	57.18	57.18	57.18	57.18	57.18	57.18	57.18
1	1	33	58.36	58.36	58.36	58.36	58.36	58.36	58.36	58.36	58.36
1	1	34	59.55	59.55	59.55	59.55	59.55	59.55	59.55	59.55	59.55
1	1	35	60.74	60.74	60.74	60.74	60.74	60.74	60.74	60.74	60.74
1	1	36	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92
1	1	37	63.11	63.11	63.11	63.11	63.11	63.11	63.11	63.11	63.11
1	1	38	63.11	64.29	64.29	64.29	64.29	64.29	64.29	64.29	64.29
1	1	39	63.11	64.29	65.48	65.48	65.48	65.48	65.48	65.48	65.48
1	1	40	63.11	64.29	65.48	66.67	66.67	66.67	66.67	66.67	66.67
1	1	41	63.11	64.29	65.48	66.67	67.85	67.85	67.85	67.85	67.85
1	1	42	63.11	64.29	65.48	66.67	67.85	69.04	69.04	69.04	69.04
1	1	43	63.11	64.29	65.48	66.67	67.85	69.04	70.22	70.22	70.22
1	1	44	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	71.41
1	1	45	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60
1	1	46	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60
1	1	47	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60
1	1	48	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60
1	1	49	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60
1	1	50	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60
1	1	51	63.11	64.29	65.48	66.67	67.85	69.04	70.22	71.41	72.60

0			46	47	48	49	50	51
S1	S2	S3						
1	1	1	.00	.00	.00	.00	.00	.00
1	1	2	2.37	2.37	2.37	2.37	2.37	2.37
1	1	3	4.75	4.75	4.75	4.75	4.75	4.75
1	1	4	7.12	7.12	7.12	7.12	7.12	7.12
1	1	5	9.49	9.49	9.49	9.49	9.49	9.49
1	1	6	11.87	11.87	11.87	11.87	11.87	11.87
1	1	7	14.24	14.24	14.24	14.24	14.24	14.24
1	1	8	16.61	16.61	16.61	16.61	16.61	16.61
1	1	9	18.99	18.99	18.99	18.99	18.99	18.99
1	1	10	21.36	21.36	21.36	21.36	21.36	21.36
1	1	11	23.73	23.73	23.73	23.73	23.73	23.73
1	1	12	26.10	26.10	26.10	26.10	26.10	26.10
1	1	13	28.48	28.48	28.48	28.48	28.48	28.48
1	1	14	30.85	30.85	30.85	30.85	30.85	30.85
1	1	15	33.22	33.22	33.22	33.22	33.22	33.22
1	1	16	35.60	35.60	35.60	35.60	35.60	35.60
1	1	17	37.97	37.97	37.97	37.97	37.97	37.97
1	1	18	40.34	40.34	40.34	40.34	40.34	40.34
1	1	19	41.76	41.76	41.76	41.76	41.76	41.76
1	1	20	42.95	42.95	42.95	42.95	42.95	42.95
1	1	21	44.13	44.13	44.13	44.13	44.13	44.13
1	1	22	45.32	45.32	45.32	45.32	45.32	45.32
1	1	23	46.51	46.51	46.51	46.51	46.51	46.51
1	1	24	47.69	47.69	47.69	47.69	47.69	47.69
1	1	25	48.88	48.88	48.88	48.88	48.88	48.88
1	1	26	50.06	50.06	50.06	50.06	50.06	50.06
1	1	27	51.25	51.25	51.25	51.25	51.25	51.25
1	1	28	52.43	52.43	52.43	52.43	52.43	52.43
1	1	29	53.62	53.62	53.62	53.62	53.62	53.62
1	1	30	54.81	54.81	54.81	54.81	54.81	54.81
1	1	31	55.99	55.99	55.99	55.99	55.99	55.99
1	1	32	57.18	57.18	57.18	57.18	57.18	57.18
1	1	33	58.36	58.36	58.36	58.36	58.36	58.36
1	1	34	59.55	59.55	59.55	59.55	59.55	59.55
1	1	35	60.74	60.74	60.74	60.74	60.74	60.74
1	1	36	61.92	61.92	61.92	61.92	61.92	61.92
1	1	37	63.11	63.11	63.11	63.11	63.11	63.11
1	1	38	64.29	64.29	64.29	64.29	64.29	64.29
1	1	39	65.48	65.48	65.48	65.48	65.48	65.48
1	1	40	66.67	66.67	66.67	66.67	66.67	66.67
1	1	41	67.85	67.85	67.85	67.85	67.85	67.85
1	1	42	69.04	69.04	69.04	69.04	69.04	69.04
1	1	43	70.22	70.22	70.22	70.22	70.22	70.22
1	1	44	71.41	71.41	71.41	71.41	71.41	71.41
1	1	45	72.60	72.60	72.60	72.60	72.60	72.60
1	1	46	73.78	73.78	73.78	73.78	73.78	73.78
1	1	47	73.78	74.97	74.97	74.97	74.97	74.97
1	1	48	73.78	74.97	76.15	76.15	76.15	76.15
1	1	49	73.78	74.97	76.15	77.34	77.34	77.34
1	1	50	73.78	74.97	76.15	77.34	78.52	78.52
1	1	51	73.78	74.97	76.15	77.34	78.52	79.71

Table A8: Winter objective function matrix

0							DECISION				
0			1	2	3	4	5	6	7	8	9
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	.00	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07
1	1	3	.00	5.07	10.14	10.14	10.14	10.14	10.14	10.14	10.14
1	1	4	.00	5.07	10.14	15.21	15.21	15.21	15.21	15.21	15.21
1	1	5	.00	5.07	10.14	15.21	20.28	20.28	20.28	20.28	20.28
1	1	6	.00	5.07	10.14	15.21	20.28	25.34	25.34	25.34	25.34
1	1	7	.00	5.07	10.14	15.21	20.28	25.34	30.41	30.41	30.41
1	1	8	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	35.48
1	1	9	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	10	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	11	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	12	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	13	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	14	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	15	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	16	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	17	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	18	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	19	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	20	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	21	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	22	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	23	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	24	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	25	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	26	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	27	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	28	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	29	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	30	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	31	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	32	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	33	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	34	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	35	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	36	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	37	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	38	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	39	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	40	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	41	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	42	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	43	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	44	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	45	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	46	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	47	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	48	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	49	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	50	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55
1	1	51	.00	5.07	10.14	15.21	20.28	25.34	30.41	35.48	40.55

0			10	11	12	13	14	15	16	17	18
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07
1	1	3	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14
1	1	4	15.21	15.21	15.21	15.21	15.21	15.21	15.21	15.21	15.21
1	1	5	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28
1	1	6	25.34	25.34	25.34	25.34	25.34	25.34	25.34	25.34	25.34
1	1	7	30.41	30.41	30.41	30.41	30.41	30.41	30.41	30.41	30.41
1	1	8	35.48	35.48	35.48	35.48	35.48	35.48	35.48	35.48	35.48
1	1	9	40.55	40.55	40.55	40.55	40.55	40.55	40.55	40.55	40.55
1	1	10	45.62	45.62	45.62	45.62	45.62	45.62	45.62	45.62	45.62
1	1	11	45.62	50.69	50.69	50.69	50.69	50.69	50.69	50.69	50.69
1	1	12	45.62	50.69	55.76	55.76	55.76	55.76	55.76	55.76	55.76
1	1	13	45.62	50.69	55.76	60.83	60.83	60.83	60.83	60.83	60.83
1	1	14	45.62	50.69	55.76	60.83	65.90	65.90	65.90	65.90	65.90
1	1	15	45.62	50.69	55.76	60.83	65.90	70.97	70.97	70.97	70.97
1	1	16	45.62	50.69	55.76	60.83	65.90	70.97	76.03	76.03	76.03
1	1	17	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	81.10
1	1	18	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	19	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	20	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	21	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	22	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	23	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	24	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	25	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	26	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	27	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	28	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	29	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	30	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	31	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	32	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	33	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	34	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	35	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	36	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	37	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	38	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	39	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	40	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	41	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	42	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	43	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	44	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	45	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	46	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	47	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	48	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	49	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	50	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17
1	1	51	45.62	50.69	55.76	60.83	65.90	70.97	76.03	81.10	86.17

0			19	20	21	22	23	24	25	26	27
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07
1	1	3	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14
1	1	4	15.21	15.21	15.21	15.21	15.21	15.21	15.21	15.21	15.21
1	1	5	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28
1	1	6	25.34	25.34	25.34	25.34	25.34	25.34	25.34	25.34	25.34
1	1	7	30.41	30.41	30.41	30.41	30.41	30.41	30.41	30.41	30.41
1	1	8	35.48	35.48	35.48	35.48	35.48	35.48	35.48	35.48	35.48
1	1	9	40.55	40.55	40.55	40.55	40.55	40.55	40.55	40.55	40.55
1	1	10	45.62	45.62	45.62	45.62	45.62	45.62	45.62	45.62	45.62
1	1	11	50.69	50.69	50.69	50.69	50.69	50.69	50.69	50.69	50.69
1	1	12	55.76	55.76	55.76	55.76	55.76	55.76	55.76	55.76	55.76
1	1	13	60.83	60.83	60.83	60.83	60.83	60.83	60.83	60.83	60.83
1	1	14	65.90	65.90	65.90	65.90	65.90	65.90	65.90	65.90	65.90
1	1	15	70.97	70.97	70.97	70.97	70.97	70.97	70.97	70.97	70.97
1	1	16	76.03	76.03	76.03	76.03	76.03	76.03	76.03	76.03	76.03
1	1	17	81.10	81.10	81.10	81.10	81.10	81.10	81.10	81.10	81.10
1	1	18	86.17	86.17	86.17	86.17	86.17	86.17	86.17	86.17	86.17
1	1	19	91.24	91.24	91.24	91.24	91.24	91.24	91.24	91.24	91.24
1	1	20	91.24	96.31	96.31	96.31	96.31	96.31	96.31	96.31	96.31
1	1	21	91.24	96.31	101.38	101.38	101.38	101.38	101.38	101.38	101.38
1	1	22	91.24	96.31	101.38	106.45	106.45	106.45	106.45	106.45	106.45
1	1	23	91.24	96.31	101.38	106.45	111.52	111.52	111.52	111.52	111.52
1	1	24	91.24	96.31	101.38	106.45	111.52	116.59	116.59	116.59	116.59
1	1	25	91.24	96.31	101.38	106.45	111.52	116.59	121.65	121.65	121.65
1	1	26	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	126.72
1	1	27	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	28	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	29	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	30	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	31	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	32	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	33	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	34	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	35	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	36	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	37	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	38	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	39	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	40	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	41	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	42	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	43	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	44	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	45	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	46	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	47	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	48	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	49	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	50	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79
1	1	51	91.24	96.31	101.38	106.45	111.52	116.59	121.65	126.72	131.79

0			28	29	30	31	32	33	34	35	36
S1	S2	S3									
1	1	1	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	1	2	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07	5.07
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1	1	11	50.69	50.69	50.69	50.69	50.69	50.69	50.69	50.69	50.69
1	1	12	55.76	55.76	55.76	55.76	55.76	55.76	55.76	55.76	55.76
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1	1	22	106.45	106.45	106.45	106.45	106.45	106.45	106.45	106.45	106.45
1	1	23	111.52	111.52	111.52	111.52	111.52	111.52	111.52	111.52	111.52
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```
0          46      47      48      49      50      51
 S1 S2 S3

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  1  1 10   45.62   45.62   45.62   45.62   45.62   45.62
  1  1 11   50.69   50.69   50.69   50.69   50.69   50.69
  1  1 12   55.76   55.76   55.76   55.76   55.76   55.76
  1  1 13   60.83   60.83   60.83   60.83   60.83   60.83
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  1  1 16   76.03   76.03   76.03   76.03   76.03   76.03
  1  1 17   81.10   81.10   81.10   81.10   81.10   81.10
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  1  1 20   96.31   96.31   96.31   96.31   96.31   96.31
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```

APPENDIX B

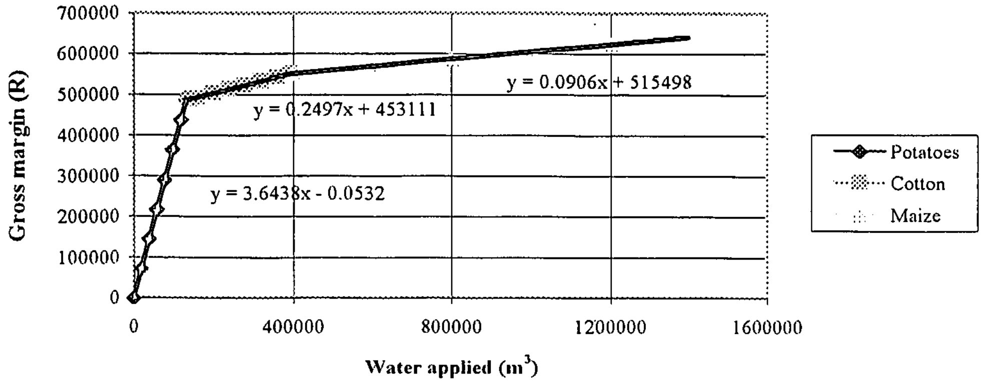

Figure B1: Gross margin as a function of water applied for180 ha farm. Summer scenario 1

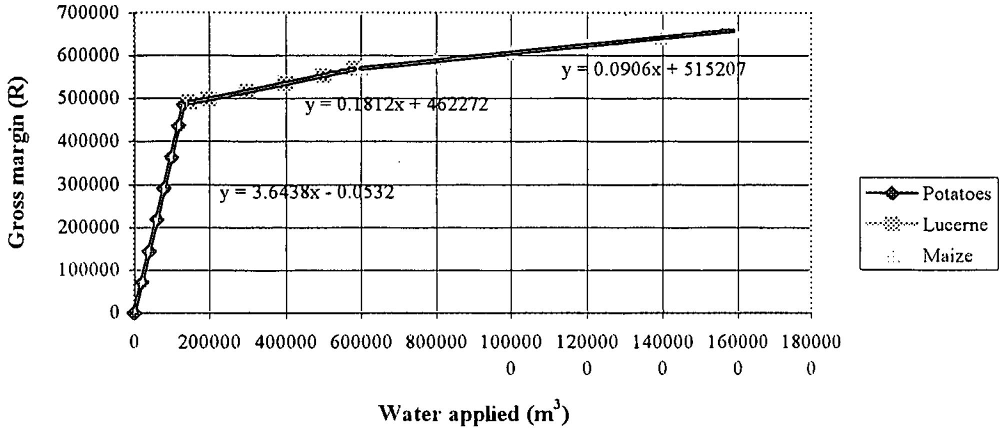

Figure B2: Gross margin as a function of water applied for180 ha farm. Summer scenario 2

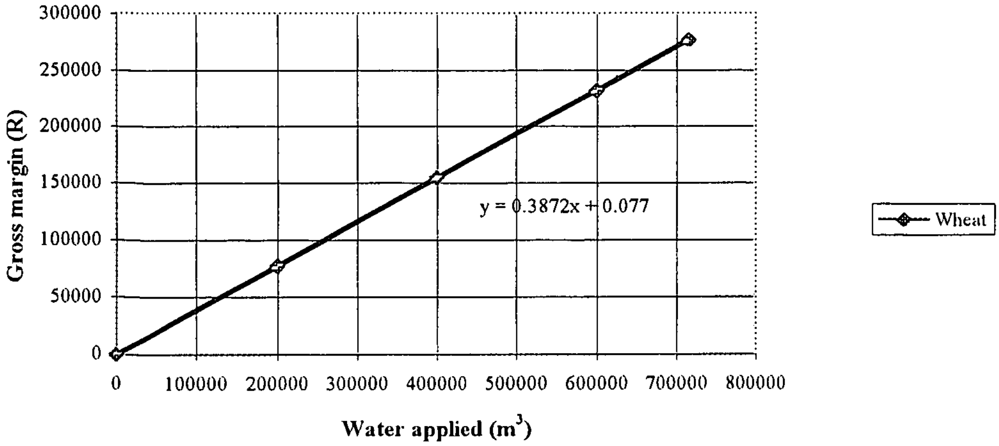

Figure B3: Gross margin as a function of water applied for180ha farm. Winter scenario

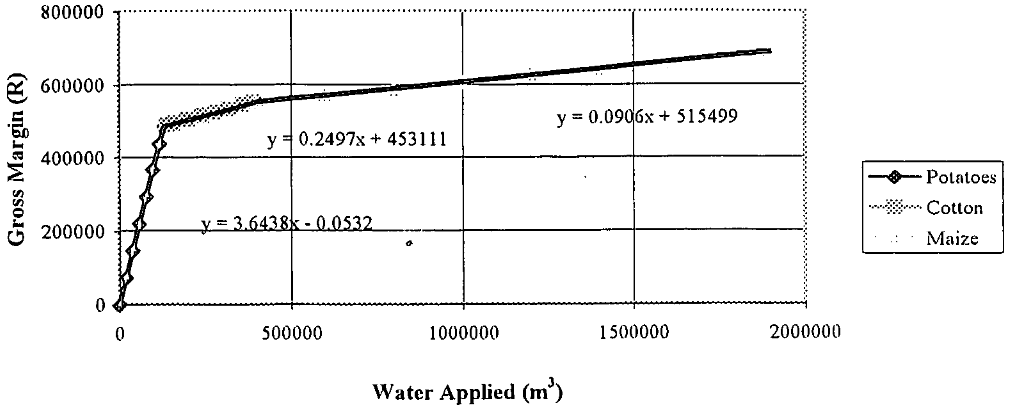

Figure B4: Gross margin as function of water applied for 240 ha farm. Summer scenario 1

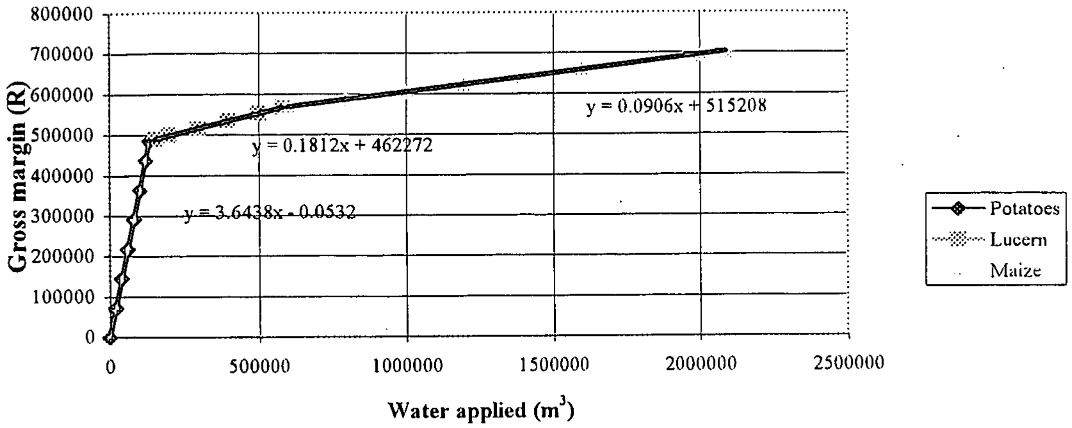

Figure B5: Gross margin as function of water applied for 240ha farm. Summer scenario 2

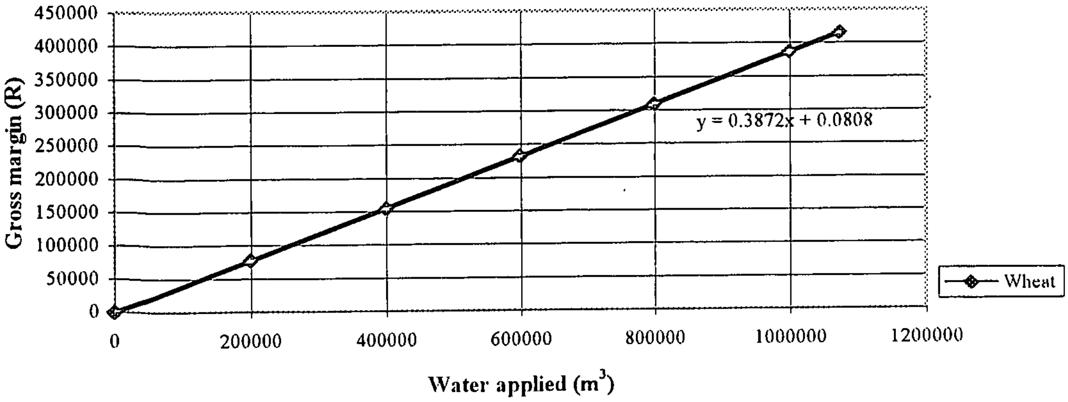

Figure B6: Gross margin as a function of water applied for 240ha farm. Winter scenario

APPENDIX C

Appendix C1: Selected provisions of the South African Water Act.

- Concerning authority to manage South Africa's water resources it is stipulated in section 3(1) that,
  "As a public trustee of the nation's water resources the National Government acting through the Minister, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons and in accordance with its constitutional mandate", also "The Minister is ultimately responsible to ensure that water is allocated equitably", and
  "...Government acting through the Minister has the power to regulate, the use, flow and control of all water..."

- Regarding the right to water use, section 4(3):
  "A person may use water in terms of a general authorisation or license..."
  General Authorisations include reasonable domestic use, animal watering, fire fighting and recreational use.

- Section 28(1) spells out the duration of permits to use water. It is stated here that:
  "The licensing period may not exceed forty years with the review periods during which the license will be reviewed, be at intervals of not more than five years."

- Addressed by water allocations are sections 43, 44 and 45:
  "In determining the quantities of water to be allocated to users, the responsible authority must consider all applications, draw up a schedule detailing how the available water will be allocated among applicants. These allocation schedules must comply with plans, strategies and criteria set out elsewhere in the Act and must give special consideration to certain categories of applicants."

- Under sections 25(1) and (2) on transfers it is stated:
  (1) "A water management institution may, at the request of the person authorised to use water for irrigation under this Act, allow that person on a temporary basis and on such conditions as the water management institution may determine, to use some or all of that water for a different purpose, or to allow the use of some or all

that water on another property in the same vicinity for the same or a similar purpose."

(2) "A person holding an entitlement to use water from a water resource in respect of

any land may surrender that entitlement or part of that entitlement;

(a) in order to facilitate a particular license application for the use of water from the same resource in respect of other land; and

(b) on condition that the surrender only becomes effective if and when such application is granted."

- Pertaining to water markets sections 26(1n) and 45(2f) stated that:

  " procedures will be prescribed for the allocation of water by means of a public tender or Auction."

- On water use charges sections 56 to 60:

  "The Minister may from time to time after public consultation, establish a pricing strategy which may differentiate among geographical areas categories of water users or individual water users. The achievement of social equity is one of the considerations in setting differentiated charges. Water use charges are to be used to fund direct and related cost of water resource management, development and use and may also be used to achieve an equitable and efficient allocation of water. In addition, they may also be used to ensure compliance with prescribed standards and water management practices according to the user pays and polluter pays principles. Water use charges will be used as a means of encouraging reduction in waste, and provision is made for incentives for effective and efficient water use"

- Provision is also made regarding information on the nations water resources in sections 139 to 145. Here,

  "The Minister as soon as it is practicable is required to establish national information systems each covering a different aspect of water resources such as a national register of water use authorisations, or an information system on the quantity and quality of water resources. This information should be generally accessible for use by water uses and the general public."

Delegation of Ministerial Powers

Provision is made in the Act for the establishment of Catchment Management Agencies (CMAs) and Water User Associations (WUAs) to facilitate the delegation of powers. The powers of these agencies are spelt out in *schedule 3* for CMAs and *schedule 5* for WUAs. A reasonable provision is made granting these bodies leverage in managing water resources. These will be discussed further when evaluating the entire institutional arrangement.