MODELLING THE POTENTIAL IMPACT OF A WATER MARKET IN THE BERG RIVER BASIN

by

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ABSTRACT

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An increasing number of economists believe that market mechanisms should be incorporated in water allocation policies. It is widely recognised that central planning as an economic system has been inefficient. In fact, it is impossible to plan efficiently from the centre, and the bigger and more open the economy is, the more impossible it becomes.

The literature abounds with models for analysing alternative water allocation mechanisms. However, the positive mathematical programming (PMP) technique, which was introduced in this study, to calibrate the regional water market, is a relatively new approach. Modelling of water markets in South Africa has received very little interest in the past. This is probably because formal water markets were not permitted in the old Water Act (1956).

The new National Water Act (1998) makes explicit provision for the transfer of water rights. However, the rules and procedures for introducing water markets have not been stipulated. To date no attempt has been made in South Africa to develop methodologies to simulate water markets. According to the new National Water Act one of the most important tasks of Catchment Management Agencies (CMA's) will be to design water allocation strategies for

each of the major catchments in South Africa. This study contributes to enhance the capacity of water authorities to make economically sensible water allocation decisions.

Without a market price, there is little or no incentive to use water efficiently. True pricing will lead to highest-value uses (e.g. drinking water and the production of high value products). Creating incentives for the most-valuable economic use of water will provide certainty; increase supply for more efficient uses, and create an even playing field for all water users including natural systems.

There are legitimate concerns that the market mechanism *per se* will not guarantee equity. Government therefore has an important role to play in ensuring that the rules and procedures exist to deal with externalities. The secret is to achieve a balance that involves interfering in the market mechanism without jeopardising the proper functioning of water markets. The functional organisation for policy-making, water allocation, water management, and monitoring of users, plays an important role in the implementation of a sustainable water development system.

OPSOMMING

MODELLERING VAN DIE POTENSIËLE IMPAK VAN 'N WATERMARK IN DIE BERGRIVIER OPVANGSGEBIED

deur

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'n Toenemende aantal ekonome glo dat die markmeganisme 'n deel van 'n waterallokasiebeleid moet vorm. Dit word algemeen erken dat sentrale beplanning as ekonomiese sisteem ondoeltreffend is. Dit is onmoontlik om sentraal doeltreffend te beplan en hoe groter en oper die ekonomie is, hoe meer onmoontlik raak dit.

Die literatuur bevat talle voorbeelde van modelle om alternatiewe waterallokasiemeganismes te simuleer. Die positiewe wiskundige programmeringstegniek, wat in hierdie studie gebruik is om die streek se watermarkmodel te kalibreer, is 'n relatiewe nuwe benadering. Modellering van watermarkte in Suid-Afrika het tot dusver nie groot belangstelling gewek nie. Die rede hiervoor is waarskynlik dat daar binne die ou Waterwet (1956) nie voorsiening gemaak was vir die instelling van formele watermarkte nie.

Binne die nuwe Nasionale Waterwet (1998) word daar wel voorsiening gemaak vir die verhandeling van waterregte, maar die reëls en die prosedures is nog nie uitgespel nie. Tot op datum is nog geen poging in Suid-Afrika aangewend om metodologieë te ontwikkel om watermarkte te simuleer nie. Volgens die nuwe Nasionale Waterwet is een van die belangrikste take van die Wateropvanggebied bestuursowerhede die daarstelling van 'n waterallokasiestrategie vir elkeen van die vernaamste wateropvanggebiede in Suid-Afrika.

Hierdie studie lewer 'n bydrae om die kapasiteit van waterowerhede te verhoog om sodoende ekonomies sinvolle waterallokasiebesluite te kan neem.

Sonder 'n markprys vir water het gebruikers min of geen insentief om water te bespaar deur dit byvoorbeeld meer doeltreffend aan te wend nie. Indien die prys van water gegrond is op die waarde daarvan vir die gebruikers sal die gebruik van water by die hoogste waarde aangemoedig word (byvoorbeeld vir drinkwater en die produksie van hoëwaardeprodukte). Deur insentiewe daar te stel vir die mees ekonomiese gebruik van water, sal nie net sekuriteit vir gebruikers geskep word nie, maar sal daar ook meer water beskikbaar wees vir gebruike waar water die doeltreffendste aangewend word. Die markmeganisme verseker verder dat daar 'n gelyke speelveld vir alle gebruikers is, insluitende die ekologie.

Daar is rede tot kommer dat die markmeganisme nie altyd gelykheid sal verseker nie. Die staat het 'n belangrike rol om te vervul om te verseker dat daar reëls en prosedures bestaan vir die hantering van eksternaliteite. Die geheim is om 'n balans te vind, wat staatsinmenging in die markmeganisme behels sonder om die doeltreffende funksionering van die mark te benadeel. Funksionele organisering vir die opstel van beleid, waterallokasie, waterbestuur en die monitering van gebruikers speel 'n belangrike rol in die implementering van 'n volhoubare waterontwikkelingsisteem.

TABLE OF CONTENTS

List of Tables

List of Figures

Chapter 1

INTRODUCTION

The defining issue of the twenty-first century may well be the control of water sources. In the next 30 years it is likely that water shortages will increase dramatically. While water supplies are dwindling because of groundwater depletion, waste and pollution, demand is rising fast. Currently 338 million people are subject to sometimes-severe water shortages, and by 2025 this number is projected to jump to 3 billion. The worsening scarcity of water threatens agricultural growth and industrial production and is likely to increase water related health problems and degrade the environment.

- M.W. Rosegrant (1997)

1.1 Background

Water resource management throughout the world is looming as one of the most important political, social, and economic issues of this century. While water allocation and water quality describe the issues of the past and the future, growing and changing social demands for available water, changing technologies and outdated laws and institutions for water allocation combine to create new challenges for economists in the next several decades. Many current problems in water allocation policy stem from a failure to recognise the connection between institutional settings, states of technology and the hydrology of water systems. These problems will continue to grow until these connections are specifically acknowledged and addressed in water policy decisions (Whittlesey and Huffaker, 1995).

According to World Resources Management (1998), water demand will by the year 2025 be determined by four major driving forces; **population, technology, trade** and the **environment**. During the latter half of the 20th century, the pressure on natural water resources in many regions of the world has been increasing dramatically. Humans extract about half of the 12,500 cubic kilometres that are readily available. Demand is now growing at twice the rate of population increase and is still accelerating. This can be attributed to the rapid growth in urban sprawl, the increased pace of industrialisation, agriculture and irrigation development and pollution. In 1995 water availability was estimated to be 7 500 cubic meters per person per year, while as recently as 1970 it was 12 900 cubic meters. Global population growth will be the predominant influence on water availability, especially in the semi-arid and arid developing countries where demographic growth will be greatest. Development aspirations of the burgeoning global population will drive the need for technologies for improving water-use efficiency, as water becomes a limiting factor in the process of increasing food production and industrialisation and maintaining the environment. Such technology will for example enable some countries to use scarce resources to produce high-value products which can be traded for food grown by more water-endowed countries, thereby enabling them to move away from the policy of food self-sufficiency to one of food security. Wastewater treatment technology to reduce agricultural and industrial pollution will also play a major role in shaping the future supply of fresh water as pollution saps the potential for growth by damaging human and environmental health.

In spite of the vital life-support service which water renders to the planet, water has historically seldom been considered to have economic value. Water was believed to be abundant, and was available to supply the socio-economic demands of the time. This situation caused water to be a non-tradeable commodity and therefore a free good. However, the continued growth in demand for water from all user sectors has considerably changed this belief over time. Today water is considered to be an economic good and a valuable asset (Anderson and Snyder, 1997).

The Dublin Principles of Integrated Water Management were adopted at the International Conference on Water and the Environment in Dublin, Ireland, in January 1992, and express a comprehensive and holistic view of water resource problems worldwide, including social, political, economic, and environmental aspects. The Dublin Statement and Conference Report express a holistic, comprehensive, multi-disciplinary approach to water resource problems worldwide. It is based on four "guiding principles" which cover environmental, social, political and economic issues:

a) Fresh water is a finite and vulnerable resource, essential to **sustain life, development and the environment.**

b) Water development and management should be based on a **participatory** approach, involving users, planners and policy-makers **at all levels**.

c) **Women** play a central part in the provision, management and safeguarding of water.

d) Water has an **economic value in all its competing uses** and should be recognised as an **economic good**.

Although the principle of water as an economic good is still not well understood or well defined, the concept has already been manifested in many regions of the world in the form of the privatisation of water supplies, the emergence of water markets, and the proliferation of bottled drinking water. This marked the end of the era of water as a free good.

According to Howe (1996b) most governments historically had classical institutional arrangements to manage the national water resource. Howe (1996b) listed those arrangements for the development, abstraction and distribution of water supplies as follows:

- Regulatory systems that issue permits for abstracting natural waters from rivers, lakes or aquifers.
- Large public or private projects that develop natural waters and provide for their distribution through contracts with water users.
- Riparian water law systems that permit 'reasonable use' of water by land owners adjacent to water bodies.
- Priority ("appropriations") water law systems that permit the establishment of water use rights characterized by priority ordering and transferability.

Howe (1996b) pointed out that regulatory systems prevail throughout Europe, the best-known examples being the Agences de Bassin of France and the Genossenschaften of Germany. Permit systems are also widely used in Canada and in some of the eastern states of the United States and Hawaii. The agencies in charge of these systems typically have the power to develop and distribute water supplies, handle waste water and, in some cases, deal with flooding. The water abstraction permits can apply for specific or indefinite periods and are typically not saleable or tradeable.

According to The World Bank (1993:9) water is an increasingly scarce resource, requiring careful economic and environmental management. The situation is exacerbated by rapid population growth and urbanisation in developing countries. As the demand for water for human and industrial use has escalated, so has the composition of the demand for water used for irrigated agriculture. At the same time, the engineering and environmental costs are much higher for new water supplies than for sources already tapped. New challenges call for a new approach. Governments have often misallocated water, and permitted damage to the environment, as a result of institutional weakness, market failures, distorted policies and misguided investments. The World Bank (1993:10) calls for particular problems to be addressed:

- Fragmented public investment programming and sector management, that have failed to take account of the interdependencies among agencies, jurisdictions and sectors.
- Excessive reliance on overextended government agencies that have neglected the need for economic pricing, financial accountability and user participation have not provided services effectively to the poor.
- Public investments and regulations that have neglected water quality, health and environmental concerns.

In order to manage water resources, a balanced set of policies and institutional reforms should be sought that will both harness the efficiency of market forces and strengthen the capacity of governments to carry out their essential roles.

The current political, social and economic climate in South Africa is ushering in a whole new era in water management. In the face of efforts to curtail runaway government spending and protect the environment, water institutions must foster the conservation and efficient allocation of existing supplies. They must also take water's growing recreational and environmental value into account. The crucial question is, can the current water institutions meet today's requirements? According to Anderson and Leal (1988) the answer is no in most cases. Current regulation of water allocation is not equipped to promote efficiency and conservation because it evolved during an era when massive capital outlay to fund huge water projects made trade-offs unnecessary. The objective was to deliver enough water to make the desert "bloom like a rose". Centralised water management, under which supplies are often allocated at highly subsidised prices on the basis of political clout, was a legacy of that era. Water may run uphill with money, but it gushes uphill to politics (Anderson and Leal, 1988).

According to South African National Committee on Irrigation and Drainage (SANCID) (1995) irrigation policy must clearly specify the rules and processes according to which change is to be negotiated in order to reduce uncertainty in a competitive economic environment. Individual entrepreneurs must be enabled, through private initiative, to continue creating wealth through profitable irrigation farming. Balanced economic growth in irrigated agriculture must be achieved through a combination of increased productivity, reallocation of rights to water resources and redistribution of income. In this process consideration should be given to productive investment, increased employment and income generation on the one hand, and to consumption, investment, provision of basic services and humanitarian relief measures on the other.

Water is often wasted because it is underpriced. Direct and indirect subsidies are still common in both developed and developing countries. Removing such subsidies and allowing water prices to rise can provide incentives for conservation and for the investment needed to develop more efficient technologies. As urban areas and industrialisation develop, often accompanied by increased concerns about its effect on the environment, reallocating water from irrigated agriculture to urban, industrial and environmental purposes becomes a major issue, in fact, a necessary condition for continuing efficient economic development (Howe, 1996b). Moreover, water often historically allocated to agricultural use may have a much higher value for urban and industrial uses (or *visa versa* considering the forward and backward linkages of agriculture). Thus, reallocating water, administratively or through the market, can reduce distortions and inefficiencies. Charging all users user fees that fully reflect costs can improve incentives for efficient use and can help to finance the much needed infrastructure to expand services to new users (World Resources, 1997-1998).

According to Easter, Rosegrant and Dinar (1998) a clear place to start with regard to more efficient water resource management policies is through the reform of existing water policies that have contributed to the current predicament. Both urban and agricultural water users receive large subsidies. These water-wasting policies can be attacked through comprehensive reforms to improve the incentives at each level of the water allocation process. Institutional and legal reforms must empower water users to make their own decisions regarding resource use, while at the same time providing a structure that reveals the real scarcity value of water.

Following the democratic change in South Africa to a new constitutional dispensation in 1994, problems arising from previous political inequalities require urgent attention. Unequal political power of the past caused imbalances in the currently apportioned water rights and lead to a skewed distribution of income. Land, water and irrigation policy reform is therefore necessary to address justifiable claims that are made to gain access to water resources (Backeberg, Bembridge, Bennie, Groenewald, Hammes, Pullen and Thomson, 1996).

The new South African National Water Act provides the framework for water markets in South Africa (Government Gazette, 1998). For the first time in South African history, water legislation makes provision for water trading as an option for water allocation. However, preference is still given to the administrative determination of the cost of water resources. In the National Water Act (1998) water markets are mentioned as a possible alternative for allocating water. It is however very vague with regard to the legal transfer of water use licences. This creates uncertainty. Furthermore, the extent of bureaucratic control and regulation of water trading in the new water legislation creates highly restrictive conditions for voluntary transfers between willing buyers and sellers (Armitage, 1999). For instance in the Berg River it has been said that no water market can be introduced before the water reserve and ecological demand for water has been determined. If an effective water market is to be introduced the above factors will have to be addressed in order to lower transaction costs currently associated with this concept.

According to Van Schalkwyk (1998), it is clear from the principles on which the new water law is based that the Department of Water Affairs and Forestry (DWAF) will follow a centralised, bureaucratic approach. In this management approach local organisations and individual decision-making for productive investments in a secure environment is impossible. The market will not be allowed to lead South Africa to a Pareto optimum situation, where the social welfare of the country will be maximised. South Africa's land reform process is based on a market approach to prevent precisely this. Nationalising water and placing it under strict government control has the same effect as the nationalisation of land would have had.

Internationally, there is enough evidence to prove that the central allocation of almost any resource gives rise to gross inefficiency. The main reason is the distortion of the value placed on resources within such a centralised planning environment. Resources are either valued too high or too low. What is the value of fresh water and how can water be allocated in such a way as to reflect the scarcity of it?

It should be clear from the above that the water allocation debate in South Africa is far from over. However, the lack of analytical tools to provide water resource management agencies with guidelines to introduce economically sensible water management policies is a major problem in South Africa. Although much research has been done in South Africa on the hydrology of river basins, the feasibility of new water supply augmentation schemes, urban and agricultural water demand predictions and water demand management (see DWAF, 1991; 1992a; 1992b; 1993b; 1993c; 1993e; 1994a; 1994b; 1994c; 1996; 1997; 1997b), there is a lack of research on water allocation mechanisms and models for analysing the outcome of alternative water allocation policies. In this study the Berg River basin will be used as a hydrological system in an attempt to develop the much-needed methodology to answer these questions.

1.2 Problem statement

Despite the resulting inefficiency and waste, traditional resource economists continue to identify taxes, regulations, subsidies and governmental allocation as solutions to today's water problems. More than anything else, that mindset reflects a deep suspicion of the market that precludes it from being recognised as a viable alternative (Anderson and Leal, 1988). In the natural resource field generally, the problem of externalities is widespread and various organisational arrangements and regulatory measures have been adopted or proposed to cope with it. Laws have been written and established by courts to protect third parties in water transfers. Often, special districts have been formed to internalise some of the externalities. The general tendency in institutional development has been to modify market procedures or completely replace them. According to Howe (1996a) institutions are slow to change in the face of technological and social evolution, usually lagging far behind in the need for more appropriate policies. This is particularly true for water resources where policy-making and administrative processes are subject to the inertia of the historical *status quo* of special interest.

Knowledge available on the optimal allocation of water clearly indicates the necessity for alternative water allocation systems (Anderson and Leal, 1988; Anderson, 1982; Backeberg *et al*, 1996; Brisco, 1996; Cummings and Nercessiantz, 1994; Easter *et al*, 1998; Frederick, 1986; Gazmuri, 1995; Howe, 1996a and 1996b; Randall, 1981; Saliba and Bush, 1987; Scott and Coustalin, 1995; Solanes, 1996; The World Bank, 1993; Thobani, 1997; Whittlesey and Huffaker, 1995; etc.). The development of a methodology to determine the potential impact of a water market is a high priority. No recent research has been conducted in South Africa on methodologies to derive demand schedules for water and to simulate water markets. Knowledge about the way in which a water market in South Africa should be introduced is lacking with regard to at least the following:

- Economic consequences of tradable water rights.
- Efficiency, economic feasibility, pricing of water rights and social welfare.
- The development of rules for improving the outcomes of allocation, that is, the principles and standards that guide public choices.
- The mechanics of integrated water management systems that will enhance more optimal water allocation. This includes the problem of reallocation to serve changing public demand while remaining sensitive to existing rights, claims and third party interests surrounding the *status quo*.

1.3 Objectives of the study

The main objective of the study is to develop a methodology to measure the potential impacts of a water market on different water users. The Berg River will be used as a case study to attain this objective. The sub-objectives of the study are:

- To determine the current water balance of the Berg River.
- To quantify the impact of different supply quantities on the value of water.
- To quantify the effect of transaction costs on the water market.
- To determine how water markets will accommodate changing water demand and use.
- To determine the impact of water restrictions, with and without water markets.

- To quantify efficiency increases because of the introduction of a water market and to determine whether the efficiency increase will be sufficient to postpone the development of capital-intensive infrastructure like the Skuifraam dam.

Although the concept of water markets is widely accepted (also in the National Water Act, 1998) experience with water markets, its functioning, rules and regulations, are very limited. Research in this field is needed to enhance the knowledge base and to prevent new mistakes.

1.4 Hypotheses

The following hypotheses guide this study:

- The value of water use rights in the Berg River is considerably higher than presently being paid for and will reflect the scarcity value of water should a water market be introduced.
- A water market will increase water use efficiency, which will result in **net water savings.** This may result in the postponement of the building of capital-intensive infrastructure like the Skuifraam dam.
- A water market will result in the withdrawal of marginal irrigation land from production.
- The water-saving strategies of farmers which result from the higher water cost will result in a higher Rand output per ha of irrigation land and m^3 of water.
- High transaction costs will erode the tradeability of water.
- A water market will be able to accommodate changing needs and demands for water.
- A water market will increase the efficiency of water demand management strategies.
- A water market will have an impact on the production decisions of water users.
- A water market will be a necessary institution for integrated water management systems.

1.5 The study area

Of all the rivers in the Western Cape, the Berg River is best suited to use as a case study for the development of a modelling approach to measure the potential impact of a water market. Reasons for this are as follows:

- A large variety of irrigation crops are produced in the area.
- The Berg River links up to a complex water supply network, which serves amongst others, the Greater Cape Town Metropolitan area.
- Almost all the problems associated with water management as discussed under the problem statement, exist in this basement.

Since there are approximately 600 farm units in the basement, it is an almost impossible task to model the whole river. The research will therefore concentrate on the area called the Upper-Berg River. This is the area from the source of the Berg River near Franschhoek to Sonquasdrift near Hermon. This area also accounts for approximately 80% of the total agricultural water use rights in the Berg River. The Cape Town Water Utility (CTWU) will be included in the study as a household and industrial water demand point. This represents the industrial and household demand sufficiently, as the CTWU also supplies water to Paarl, Franschhoek, Wellington, Stellenbosch and the Western Cape Regional Services Council. The Swartland and Saldanha schemes are not included in the study as the combined demand from the two are less than 10% of the total demand for urban water.

1.6 Research method

The methods and techniques used are descriptive, theoretical, philosophical and analytical, and based on economic principles. A defensible theoretical structure is developed to examine data intuitively and to permit comprehensive evaluation. This theoretical structured model is subsequently used to analyse the impact of a water market. A non-linear modelling approach is followed. The model is written in GAMS notation and solved with the CONOPT2 solver. Positive mathematical programming (PMP) is used for model calibration. This approach makes this study different from previous research in the same field and allows the researcher to analyse the magnitude of the influence of certain variables from the base run in a more flexible way.

The following steps were followed to conduct this study:

- A literature review which included the theory of the true value of water, water rights, markets and pricing, the impact thereof on irrigation agriculture, methodology to determine the value of water rights and models to analyse the impact of water markets and competition between water users, was conducted.
- An investigation into the present water supply system, the demand for and supply of water, the cost of water, agricultural production systems and practices and the allocation of water and water rights.
- Division of the Upper-Berg River into homogenous areas for modelling and crop budget purposes.
- Compilation of crop budgets for the different homogenous areas under different water application and crop combination scenarios.
- Development of typical farm models for the different homogenous areas and irrigation systems.
- Development of a model to simulate the introduction of a potential water market in the Berg River basin.
- Calculation of the value of water use rights for agricultural as well as urban water users at different water supply quantities.
- Determination of water values with and without water trade; scenarios included different water supply and demand levels.
- Quantification of the impact of transaction costs on the efficiency of a water market.
- Quantification of the effect of different water costs on the efficient utilisation of water and on optimal production practices.

1.7 Data used

In order to construct a mathematical programming model which accurately represents the Berg River system, various sources were consulted. A farm survey was conducted in the Upper-Berg River with a structural questionnaire using a representative sample of 115 farms representing the seven main irrigation regions of the Upper-Berg River.

Enterprise budgets were compiled with the Micro-Combud (Micro Computerised Budget system) program of the Department of Economic Affairs, Agriculture and Tourism of the Western Cape. This system ensures that the budgets all comply to accepted agricultural economic norms. Price and yield data were obtained from the Chair in International Agricultural Marketing and Development (CIAMD) of the University of the Free State. CIAMD collects and processes this data for the Deciduous Fruit Producers Trust (DFPT).

The capacity of the various irrigation systems and schemes was obtained from irrigation experts as well as from the water fiscals of the Irrigation Boards in each area. Information on irrigation schedules and demands for various crops was obtained from the Institute for Fruit and Technology (INFRUTEC) of the Agricultural Research Council (ARC) in Stellenbosch. They also provided information about deficit and supplemental irrigation practices.

Most of the urban demand data was obtained from the Department of Water Affairs and Forestry (DWAF) (1991, 1992a, 1994b and 1997a). The Cape Town City Engineers Annual reports (1980 to 1999) were also used to calculate urban demand growth over time and to calculate seasonal use patterns. The Palmer Development Group of consulting economists provided information on international experiences with regard to the demand elasticities for water (Palmer Development Group, 2000). For the purpose of this study the household elasticities calculated by Veck and Bill (1999) were used (see Section 2.6.1) and for the commercial and industrial uses the average from the literature reviewed by the Palmer Development Group (2000) was used.

The compilation of a water balance for the Upper-Berg River was based on the hydrological figures calculated by the Ninham Shand Group of consulting engineers (DWAF, 1993b; 1993c; 1993d; 1993e; 1994a; 1997b). The same sources were also consulted for information on alternative water supply augmentation schemes for the Western Cape.

1.8 Chapter outline

The study is primarily concerned with the development of a methodology to measure the potential impacts of a water market on different water users. The present chapter is followed by an extensive literature review on issues relating to water markets. The chapter concerned deals with water use rights in South Africa, water resource management, the economic value of water, water allocation systems, the characteristics of water markets, an international perspective on water markets and an overview of modelling approaches followed.

Chapter 3 presents a comprehensive description of the Berg River basin, a water balance for the Berg River, an overview of the sampling process, the survey results and a description of the typical farms. This is followed by the mathematical specification of the spatial equilibrium model in Chapter 4.

In Chapter 5, the positive mathematical programming (PMP) technique is employed to calibrate and to validate a base model for the Upper-Berg River. After this chapter several applications follow to show some of the impacts of a water market. Chapter 6 analyses the effect of water trade on efficiency and the optimal allocation of water. Chapter 7 deals with the impact of transaction costs on water trade.

The final chapter consists of conclusions and recommendations.

Chapter 2

LITERATURE REVIEW

In the natural resources management field, appropriate application of markets calls for political choices that are not excessively coloured either by the neo conservative prejudice that markets can fix everything or by the liberal and environmentalist concern that markets are the stalking horse of political reaction.

- John Paterson (1987)

2.1 Introduction

The intention of this chapter is to provide the reader with a background regarding water use rights in South Africa, mechanisms for allocating water, the value of water use rights and the management of water resources. The chapter was written after an exhaustive list of literature on topics relevant to this study had been consulted. The review starts with an overview of water use rights in South Africa. A discussion on different approaches to water resource management follows. The fourth section deals with the economic value of water and a description of the concepts of the cost and value of water. It provides an overview of the alternative water allocation mechanisms and relates the value of water to the optimal allocation of water. This is followed by a section elaborating on the characteristics of water markets and market imperfections. The sixth section discusses some practical aspects to consider in the implementation of water markets. An international perspective on water markets follows. The chapter is concluded with an overview of the different modelling approaches followed by other researchers of water markets.

2.2 Overview of water use rights in South Africa

It is not the objective of this section to provide an in depth discussion of the old and new South African water laws. A brief overview of the main characteristics with regard to water rights that were applicable in the old water law, Water Act, 1956 as well as those in the new water act, National Water Act, 1998, is however provided.

2.2.1 The old Water Act (Act 54 of 1956)

Backeberg *et al* (1996) deals extensively with all the important issues pertaining to water rights which were contained in the old water law, Water Act, 1956. This section is largely based on this work and is included for the sake of completeness.

This law incorporated and amended many of the historical developments in water law over a period of about 300 years. It was an amalgamation of certain of the legal principles of Roman Dutch Law and English Law, supplemented by rules developed in South Africa for specific conditions. It was based on the riparian right doctrine of English Law, which is partially tempered by the reintroduction of the so-called *dominus fluminus* doctrine of Roman Dutch Law. Another 33 acts dealt with water use rights to use water out of specific schemes or works within certain demarcated areas. Water Act (1956) regulated the control, conservation and use of water. The power to exercise authority was vested in the Minister of Water Affairs and Forestry. Water rights were not contained in the Water Act (1956), as this Act only contained the mechanisms for determining and obtaining water rights. Water rights were contained in various documents, including notices in the Government Gazette, schedules for Government water schemes, schedules for irrigation boards, Water Court orders, purchase contracts, deeds of transfer, deeds of servitude, written permissions by the Minister of Water Affairs and Forestry and Acts dealing with specific water schemes, works or areas. For many properties such documents did not exist and must still be determined even after the new National Water Act, 1998 was approved.

The section of the Water Act (1956) that deals with water rights were based on two cornerstones:

- The first cornerstone was the distinction between two categories of water, namely private water, which for the sake of simplicity included groundwater and public water. In addition, public water consisted of normal flow and/or surplus water. This was mainly due to the influence of Roman and Roman Dutch Law on the development of the law. The main distinction between public and private water was that public water flowed in a known and defined channel and was capable of irrigation on two or more pieces of land, which were original grants riparian to that stream. Private water on the other hand, was water not derived from a known and defined water channel, or if it was derived from a known and defined channel, then it was not capable of irrigation on two or more pieces of land which were original grants. The normal flow of a public stream was limited to the maximum quantity of water available for beneficial irrigation during peak demand, but without storage, usually during the three to four months immediately preceding the rainy season. Surplus water, on the other hand, could be used for beneficial irrigation only after it had been stored.

- The second cornerstone was a distinction regarding rights. Rights to use groundwater and public water differed between areas not declared as Government water control areas and areas declared as such. Furthermore no property rights to public water existed, but only a right for certain persons to use the water subject to certain conditions. In an area not declared a Government water control area, all the owners of land held under original grants or deeds of transfer, and the sub-divisions of such land, next to a public stream, had common property rights to all the water in that stream and each of them had a right to a share in that water for irrigation and urban purposes. This was mainly due to the influence of English Common Law on the development of the old water law. However, these rights were restricted, as many mechanisms had been created to allow other persons to obtain rights to use a share of the water. In an area declared as a Government water control area, the rights to the use of groundwater and public water were vested in the Minister of Water Affairs and Forestry, subject to the beneficial exercise of certain rights. This was due to the partial reintroduction into the old water law of the Roman Dutch Law doctrine *dominus fluminus.*

The rights to private water on the other hand, excluding groundwater, could not be affected by declaring an area as a Government water control area. An owner of land on which groundwater (in an area which was not declared as a Government water control area) or private water was found, had the sole and exclusive use and enjoyment of such water. It can therefore be argued that there were unlimited property rights to these waters. This was mainly due to the influence of English Common Law on the development of the old Water Act.

The system of surface water rights, comprising 90 percent of available water resources in South Africa, was based on riparian ownership. This linked water rights to land ownership or use. According to the 1956 Water Act there were no ownership rights, and decision-making powers regarding the transfer of various types of rights rested with the Minister of the Department of Water Affairs and Forestry (DWAF). A gradual relaxation of central control over water management occurred since the mid 1980's. Amongst others, changes in water management have influenced the limited transfer of management responsibilities to farmers on state irrigation schemes, and the deregulation of certain water management decision-making powers to the DWAF officials in certain catchments areas (Backeberg, 1994; Backeberg, 1997).

The discussions and consultations surrounding a new South African Water Act started in 1995 and progressed to the drafting of the National Water Act (Act 36 of 1998). The new Water Act moved away from private ownership of water rights and appointed the government as the custodian of the nation's water resources.

2.2.2 The new National Water Act (Act 36 of 1998)

The National Water Act (1998) identifies sustainability and equity as the central guiding principles in the protection, use, development, conservation, management and control of water resources. These guiding principles recognise the basic human needs of present and future generations, the need to protect water resources, the need to share certain water resources with other countries, the need to protect social and economic development through the use of water and the need to establish suitable institutions in order to achieve the objectives of the new act. These objectives are to be achieved through a massive administrative system that must be self-financed primarily by the users of the water resource.

The new National Water Act (1998) stipulates that all existing claims to water rights had to be registered within a reasonable time period. On completion of the registration process (in January 2001) and the establishment of a comprehensive data base on water users, the starting point for the pricing strategy will be the water management area. Through geohydrological assessments and the use of hydrological models, the Department of Water

Affairs and Forestry will calculate the available water for each water management area. From this quantity, five deductions will be made to determine the total water that can be allocated:

- Private usage (Schedule 1 of the Act). This represents the reasonable usage for domestic, small gardening (not for commercial purposes), the watering of animals (excluding feedlots) which graze on the concerned land, but not exceeding the grazing capacity, emergency (i.e. fire extinguishing) and waste discharge purposes as well as sewerage systems such as in rural and local government areas. Irrigation and other commercial agricultural activities are therefore excluded from this allocation.
- Basic human needs (i.e. the first component of the Reserve). This component provides for basic human needs and includes water for drinking, food preparation and personal hygiene. Unofficially an estimated 25 litres per person per day will be allocated for this need.
- Long-run ecological sustainability (i.e. the second component of the Reserve). This component will ensure that sufficient water and good quality water will be reserved to sustain the ecology of the water resource.
- International obligations. This allocation is relevant for instance where inter-country water schemes exist e.g. Lesotho Highland water scheme.
- Inter-basin transfers (i.e. water taken from one catchment area to augment water supplies in another area). In certain cases, a charge will be levied in this regard depending on the circumstances and objectives of the inter-basin transfer.

The above quantity claims will be excluded from the pricing strategy which, by implication, implies that the users of the remaining water resources (including irrigation farmers) will to a certain degree subsidise the provision of the above allocations. The Minister of Water Affairs and Forestry, with the concurrence of the Minister of Finance, will then, with notice in the Government Gazette, determine a water pricing strategy for any other water use. This pricing strategy may contain a strategy for setting water use charges:

- for funding water resource management (i.e. the Catchment Management Agencies);
- for funding water resource development and the use of waterworks (i.e. government water schemes);

- for achieving the equitable and efficient allocation of water (i.e. correcting past injustices and to ensure optimal utilisation, which implicates an increase in water prices for agricultural purposes).

The general approach to the pricing strategy will thus be one where the water user has to pay the entire cost of provision, management and the servicing of the water resource and waterworks, whichever applies to the specific water management area. In essence this means that agricultural producers using irrigation will also pay for bureaucratic structures for the administration of water.

The following key aspects have been identified with regard to the new National Water Act (Danhauser, 2000; Van Schalkwyk, 1998; Backeberg *et al*, 1996):

- Water ownership rights have shifted from the private hands of the landowner to the collective hands of the state. The separation of the ownership of land and water and the substitution of water rights with a licence will lead to a reduction in land values. This situation will negatively influence the net wealth of irrigators and the security position of financiers as well as their involvement in agricultural finance.
- Sustainability and equity presents the guiding principles in the protection, use, development and management of water resources.
- The new act gives priority to basic human needs for water as well as ecological sustainability (the reserve) above that of agriculture and other industries.
- South Africa has been divided into 18 Water Management Areas. For each area, Catchment Management Agencies and Water Users Associations should be established, the former to manage water supply and the latter to collectively lobby for rights to water.
- The new Act respects existing water rights and farmers may continue using water until a call is made for the application for licences.
- A general authorisation has been published, authorising certain areas to use water without a licence. Limits are, however, stated and registering is required if the limits are exceeded. Regulations for both surface and groundwater were issued.
- All significant water users that are excluded from the general authorisation have to register their water use.

- Not registering will have detrimental effects on the allocation of water licences later. If a user did not register existing water rights they will be treated as new applicants when the licensing process commences.
- Given the fact that water licences have a time span of 40 years, and are subject to a review process at intervals not exceeding 5 years, long-term planning and investment in agriculture is complicated. This is especially true for long-term crops and irrigation equipment.
- From now on water supplied by the DWAF will be priced at its true economic cost. This implies that the farmer will have to pay the capital, operating and maintenance costs of the entire water supplying system and consequently water tariffs can be expected to increase.
- Increases in water tariffs will imply increased pressure on the profitability and cash flow of farmers in South Africa.

2.3 Water resource management

The US Office of Technology Assessment (1993) distinguishes between essentially three main categories of water management:

- Water supply management
- Water demand management
- Integrated water management

2.3.1 Water supply and demand management

The U.S. Office of Technology Assessment (1993) pointed out that historically most governments attempted to solve the growing demand for water resources by following a water supply management approach. This approach was very costly in terms of capital investment and involved the building of new dams and water infrastructure to satisfy the growing demand for water. The approach gave rise to several problems such as:

- The perception by the public that water is not a scarce and valuable resource. This is probably the most difficult change to accomplish.
- Water works were not optimally designed for water saving strategies.

- There were very few incentives for the development of water saving technology as water was cheap and often subsidised (especially for agriculture).
- The environment paid the bill for water waste practices and pollution due to excess irrigation and other waste.

South Africa was no exception. Governments of the past did exceptionally well in building new infrastructure to satisfy the growing water demand (for examples see the following White Papers, W.P.U.-65, 1965-1966; W.P.BB.-66, 1966-1967; W.P.F.-67, 1967-1968; W.P.D.-67, 1967-1968; W.P.V.-68, 196-1969; W.P.K.-68, 1968-1969; W.P.N.-72, 1972-1973; W.P.P.-78, 1978-1979). Few countries in the world could afford to continue on this path and started gradually, as water sources became scarcer, to implement so-called water demand management practices.

Opportunities exist for significant gains in water-use efficiency through the better management of existing (i.e. developed) water supplies. Such opportunities may be realised by (U.S. Office of Technology Assessment, 1993):

- improving the co-ordination of water resource management;
- enhancing the flexibility of reservoir and reservoir-system operations;
- expanding the conjunctive use of ground and surface water; and
- taking advantage of new analytical tools and forecast systems.

The Western Australian Water Resources Council (1986:1) defines water demand management as "The programme, which is adopted to achieve effective management of the use of water resources in order to meet the general objective of economic efficiency, environmental conservation and community and consumer satisfaction".

The principle objectives to be achieved through water demand management are:

- to restrain demands for capital at a time when available funds are limited and borrowing is expensive; and
- to promote the efficient use of water, thus easing competition for water resources and helping to minimise the pressure on the natural environment.

The action needed to achieve these objectives is not restricted to water authorities. Most importantly, it requires that there be changes in community attitudes and behaviour. It will therefore be important to promote an understanding of the factors affecting water use, and to encourage an active community interest in the use of water. The water demand management approach concentrates on techniques and technologies to curtail runaway water demand growth by implementing water saving strategies. These strategies focus on the more efficient use of existing water infrastructure and supplies.

Efficiency gains from permanent measures could offset or postpone the building of large and costly structures that might otherwise be needed to deal with climate change and other factors leading to increased demand. Demand-management measures are also important because they often have short payback periods and lead to reduced capital and operating costs for water supply and wastewater treatment facilities. Water saved through demand management can be made available to protect wetlands and fish and wildlife habitats, and reduced waste water and drainage flows can yield additional environmental advantages (U.S. Office of Technology Assessment, 1993).

As important as conservation may be, it does have its limits. In areas where comprehensive conservation has begun, demand management may not yield large additional savings (Miller, 1989). To the extent that conservation is successful and growth in demand continues (e.g. through increases in population), long-term water-management flexibility through decreased water use will be more difficult to achieve. The limits of conservation are far from being reached, but in the absence of new developments in conservation technology, conservation can be expected to have diminishing returns. Ultimately, additional solutions may be needed. Moreover, once the easy options have been implemented, additional conservation may require higher costs and important lifestyle changes, and these may be resisted by the public.

Tsiourtis (1996) is of the opinion that water demand management is not always acceptable to consumers and more pointedly, farmers. Farmers see it as a restriction on their freedom to cultivate anything they wish and usually argue that it will result in income reduction. The government, on the other hand is obliged to provide water to a wider range of population and has the responsibility to ensure that limited water resources are used in the most efficient and effective way. Of course this requires that the decisions made are justifiable and well documented and those most economically hurt are compensated satisfactorily.

Winpenny (1994) argued that managing demand entails taking into account the value of water in relation to its cost of provision, and introducing measures which require consumers to relate their usage more closely to those costs. It entails treating water more like a commodity, as opposed to an automatic public service. Water must therefore be treated as an economic good. Mirrilees, Foster and Williams (1994) are of the opinion that tradeable water rights have been most appropriate for dealing with direct abstractions as they occur in agriculture and in the allocation of water between local authorities. They do not have as much scope for application among individual urban users due to the complexity of the system required for success. Water users for whom water has low use-value will have an incentive to use water economically and to sell or lease their rights for spare water. Water users for whom water has high use-value will have an incentive to lease or buy water rights in order to expand their activities.

2.3.2 Integrated water resource management

According to Howe (1985) the current widespread interest in water markets is symptomatic of the underlying inflexibility of existing allocative conventions. While markets command a great deal of attention from an economic viewpoint, they comprise only a subset of possible options for dealing with this underlying problem.

Serageldin (1996) states that the present path, where water resource management is characterised by policies that are unsustainable from an economic, social or environmental perspective, cannot be continued. There is a multitude of problems, but all stem from four principal failures:

- The refusal to treat water as an economic good.
- Excessive reliance on the government for water and waste-water services.
- Fragmented management of water between sectors and institutions, with little regard for conflicts or complementarity between social, economic and environmental objectives.
- Inadequate recognition of the health and environmental concerns associated with current practices.

Serageldin (1996) is of the opinion that a new approach should be adopted to water resource management in the new millennium so as to overcome these failures, reduce poverty and conserve the environment, all within the framework of sustainable development. This approach should include the following:

- Quantity and quality concerns should be addressed through an integrated approach.
- Land use management and sustainable water management should be integrally linked.
- Freshwater, coastal and marine environments should be recognised as a continuum, with significant implications for strategy, planning, management and investment actions.
- Water should be recognised as an economic good and cost-effective interventions must be promoted.
- Support to innovative and participatory approaches.
- Focus must be on actions that improve the lives of people and the quality of their environment.

Serageldin (1996) pointed out that water is an indispensable resource, which may limit future development in parts of southern Africa. The region has an uneven and unreliable rainfall distribution, being vulnerable to almost endemic droughts and sporadic floods, particularly since the early 1980s. Yet many water management problems affecting sustainable development remain unresolved. According to Serageldin (1996) water issues need to be treated in a systematic way. Sectoral water management by its separated uses must cease, instead a comprehensive framework for water resource management must be developed. Coordination between different sectoral users is critical if this is to be sustainable. Land use and water policies and management need to be linked, and physical and institutional infrastructure must be complementary.

Shela (1996) argued that inadequate strategic planning and water resource development underscore social and economic vulnerability. The southern African region experiences chronic food shortages, reduced agricultural incomes, waterborne diseases, growing impoverishment, deteriorating health, a degraded environment and lessened regional and national economic security. Rapid population growth and urbanisation compound problems surrounding human development, water scarcity and the conservation and protection of water resources. The need for countries to share watercourses provides awesome challenges in water rights issues and the equitable utilisation of the common water to avoid environmental, political and economic conflicts. Out of many water management concerns in southern Africa, the scarcity and vulnerability of water and related services, the degradation of land and water resources, the challenges of sharing water between countries, and the need for a sound institutional framework to promote integrated water management, are particularly important. Rogers, Bhatia and Huber (1996) suggested that the blueprint for water policy should be Chapter 18 of Agenda 21 adopted at the 1992 UN Conference on Environment and Development:

"Effectively integrated management of water resources is important to all socio-economic sectors relying on water. Rational allocation prevents conflict and enhances the social development of local communities, as well as economic planning and productivity. Efficient demand management allows water-using sectors to achieve long-term savings on water costs and stimulates resource conscious production technologies. Health conditions and environmental quality should also improve either as a result of integrated development planning or as beneficial consequence of improved environmental or social conditions."

According to World Resources (1997-1998) the adoption of a comprehensive framework facilitates the consideration of relationships between ecosystems and socio-economic activities in river basins. Analysis should take account of social, environmental and economic objectives; evaluate the status of water resources within each basin; assess the level and composition of projected demand; and take into consideration the views of all stakeholders. The advantages of such an approach are:

- Ability to better consider both short and long-term demands for water in an economically efficient manner.
- Ability to integrate activities and objectives that are not always feasible in separate approaches.
- Enhanced ability to manage the resources with a view to environmental issues.
- Ability to benefit from cost reductions through economies of scale.
- Ability to find efficient solutions to water quality and pollution problems.

- Facilitate action of reaching a consensus among the riparians, thereby reducing tensions and conflicts.
- Provide a means to assure equity and participation of beneficiaries and those impacted by development.
- Ability to adjust to changing priorities.
- Ability to prepare for emergencies such as drought and floods.
- Provision of a base for research and knowledge accumulation.

Smith (1988) pointed out that the introduction of water markets is part of an integrated water management strategy. Water reallocation is facilitated by allowing water to be marketed, that is, transferred from willing sellers to willing buyers. Water marketing is an important means of transferring accurate price signals regarding the value of water and is therefore closely linked to demand management. If owners of inexpensive water are allowed to sell it at higher market prices, they will have an incentive to conserve, and those willing to pay higher prices for water are unlikely to do so only to use it inefficiently. According to Thobani (1998) three market-based approaches to water management show potential for meeting water needs: opportunity cost pricing, informal water markets, and formal water markets. Because of certain practical and political difficulties, publicly administered opportunity cost pricing is usually unworkable. Informal markets, which evolve spontaneously in response to inflexible methods of water allocation, can quickly lead to improved water use. They are also easy to implement politically. However, their illegal and unregulated nature often results in problems. Formal water markets have greater potential for success.

Duda (1998) is of the opinion that international consensus has emerged and that a more comprehensive, cross-sectoral approach is needed to protect water resources; an approach that integrates ecological and development needs, and is based on holistic analysis of the carrying capacity of the water environment. In this approach, a river basin, groundwater system, coastal area or large marine ecosystem typically serves as management unit on which constructive changes for sectoral development policies and activities can be based, as well as for how priority environmental interventions can be made.

If all the facts stated above are taken into consideration it is not unrealistic to say that countries will have to "adapt or die". Countries which cannot address the challenges of integrated water management practices will in future years experience a comparative economic disadvantage and will probably be faced with political instability and an economy sliding into poverty. The way in which water is allocated and priced is a major component of integrated water management. These two topics are discussed in the following sections.

2.4 Water allocation systems

Howe, Schurmeier and Shaw (1986) pointed out that the evolution of priority water rights systems occurred in response to needs in water-short regions where many uses were located away from the river. In the western United States, this evolved from practices in 19th century mining camps where water was transferred away from the natural streams to ore processing facilities. Security of tenure was needed, so the rule became "first in time, first in right". Similar developments took place in Australia and Chile. According to Howe *et al* (1986) priority water rights have come to be characterised by:

- A priority system with senior rights having first call on available water.
- Quantification in terms of diversion flow rates, consumptive volume, type of use, place of diversion and seasonal time of use.
- Saleability, subject to "no injury" to other water users.
- A "beneficial use" requirement.

Howe *et al* (1986) found that priority systems are spreading as water scarcity increases. They seem the best systems to fit a set of desirable criteria for water allocation mechanisms: (a) flexibility in allocation over time; (b) security of tenure for water owners; (c) reflection of the real cost of water to the user; and (d) fairness to participants. The priority system clearly corresponds to these: (a) water rights are personal property and are saleable; (b) sales of water rights are voluntary, and so they can be held as long as the owner desires; (c) water rights prices, when set in fairly competitive markets, reflect real opportunity costs (in contrast to the arbitrary, often politically motivated, pricing of water from large projects); and (d) transactions between willing buyers and sellers appear to meet the test of fairness.

Water allocation can be done by either of two institutions (Cummings & Nercessiantz, 1994):

- A decentralized institution wherein all users obtain the resource in a competitive market. Competitive forces result in a market price that reflects the relative scarcity of the resource. Decision makers are therefore forced to include the opportunity cost of water in their production decisions. Barring market failure, this process is expected to equalise marginal values and utilities.
- The second possibility is a centralised institution wherein a central manager who knows the scarcity value of the resource, as well as its marginal values and utilities, and distributes water in such a way that total utility is maximised, controls the resource. In theory, if the manager has perfect knowledge and insight, the ultimate allocation of resources will be identical under the two institutions, with the latter probably costing much more.

The main problem with a centralised institution is that if it has to achieve an optimal or near optimal situation, it requires giant allocative models that have not been developed successfully anywhere in the world. Such a model can hardly be constructed satisfactorily - It will by necessity (or rather conveniently) contain too many subjective elements. In addition, decisions to change allocations or to increase water tariffs are often likely to spur on resistance and agitation, with the result that decisions may become vehicles of political patronage and convenience rather than efforts to maximise the public welfare (Cummings & Nercessiantz, 1994). There are substantial differences between the alternatives, which are discussed in the following sections.

2.4.1 Centralised allocation systems

The riparian system of water law found in the United Kingdom and (by inheritance from there) in the eastern United States and South Africa (before 1998) allows owners of land bordering on water bodies "reasonable use" of the waters in terms of quantity and quality. The evolution of riparian law from earlier Roman and English laws illustrates how law changes slowly in response to changing social needs. The Roman and early English water laws were laws of "prior occupancy", i.e. the earliest users along a river or canal were protected against damage caused by those of later comers. While this seemed equitable, it served to deny water use to new, often more productive enterprises as the industrial revolution progressed. A more flexible sharing of water was needed, so the English courts evolved the riparian doctrine, and civil actions resolved disputes. This was established in regions of plentiful water supply where one party's "reasonable use" did not frequently interfere with the uses of others. Where water is truly scarce and/or where water quality problems are important, the riparian doctrine simply does not work and many eastern states of the United States are now changing their systems (Colby, 1990).

Many authors (e.g. Van Schalkwyk, 1998; Backeberg *et al*, 1996; Louw and Van Schalkwyk, 1998; Anderson, 1982; Brisco, 1997; Rogers, 1996; Solanes, 1996; Thobani, 1995) disagree with the notion that centralised planning is the solution to the problems of natural resource allocation in general and water allocation in particular. They recognise the shortcomings of competitive markets, but doubt whether the government will do any better. Apart from the questionable motivation of a central planner to behave in such a way as to allocate resources efficiently, there is the question of his ability to do so.

According to Anderson (1982) such thoughts are based in part on new resource economics (NRE) paradigm, which provides a clearer understanding of the problems of water allocation. The focus of the NRE is on individual decision-makers, be they buyers and sellers in the private sector or bureaucrats and politicians in the public sector. In the case of water allocation, there has been an implicit reliance on (some would say a blind faith in) the ability of the few decision makers within a centralised structure to act objectively, omnisciently and responsibly in pursuit of the public interest. The NRE economists ask whether decentralised markets with well-defined property rights could do better.

Thobani (1995) states that the track record of administered systems of water allocation has not been impressive. Despite growing water scarcity and the high costs of water supply infrastructure, water is typically underpriced and used wastefully, the infrastructure is frequently poorly conceived, built, and operated, and delivery is often unreliable. Water quality has not been well maintained, and waterlogging and salinity have not been properly controlled. Thobani (1995) is of the opinion that these systems also have tended to favour the relatively wealthy. Wealthier farmers manage to obtain easier access to water rights, which are usually obtained without charge and for which use farmers pay only a small fraction of the cost of building and operating the associated irrigation infrastructure. Similarly, while the better-off residents in many cities in developing countries enjoy access to cheap municipally supplied water, many of the poor in the same cities must resort to very expensive private water truckers to meet their daily needs.

Howe (1998) pointed out that the problems with non-tradable permit systems under conditions of water scarcity are clear. An administrative board that does not have the information required to achieve economic efficiency and equity carries out allocation, and the allocation is likely to be rigid over time and not responsive to changing social values. Large public or private projects generally develop a natural water source by providing storage and distribution. Access to the natural water supply (say a river of variable flow) must be acquired according to the national or regional system of water law, while the developed water supply is usually allocated to customers through contracts. In many cases, these contracts tie the water supply to specific uses (such as irrigation) or even specific lands. These constraints lead to increasing inefficiency as economic and social needs change. However, this need not happen, for some projects have developed flexible, market-like arrangements for the allocation of water. According to Howe (1998) the water markets of the Northern Colorado Water Conservancy District that distributes water from the United States federal Colorado-Big Thompson Project, are internationally known for their efficiency and adaptability.

2.4.2 Market allocation systems

If property rights in water use were fully defined and transferable, each owner would incur the full costs and benefits of his actions. An owner who ignores the need to allocate water to higher-valued uses, would see his personal wealth decrease. Thus, knowledge and incentives would be linked. That is not the case when property rights in water are "owned" by the government. Irrigators may derive benefits from water supplied by public works projects, but they are not at liberty to transfer the water to non-agricultural uses even when such reallocations would be of higher value. The actions of the "owner", or the agency official that authorises water use, are not directed by the value of competing uses, as would be the case in a market setting, because he would not gain monetarily from such transfers and could in fact lose discretionary power. Disallowing voluntary trades and restricting water use to irrigation are ways of ensuring that agency control will be maintained (Anderson, 1982).

Many authors (e.g. Anderson, 1982, 1983 and 1985; Cummings & Nercessiantz, 1994; Easter Rosegrant and Dinar, 1998) pointed out that there are other important differences between market and centralised allocation. Water markets would send supply and demand signals that would enable managers to conserve water and co-ordinate its use, precisely the type of information that is conspicuously absent under centralised allocation. Water markets would also allow decentralised knowledge to be brought to bear on water management decisions. A farmer can apply his first-hand knowledge of his land, local hydrology, irrigation technology, and relative profitability of alternative crops to decide how much water to apply and which crops to grow on his land. Because they lack such information, public officials are typically forced to use comprehensive plans that are not appropriate under the circumstances. It has been shown by Backeberg *et al* (1996) that models used by bureaucratic decision-makers in South Africa were flawed. In the development of the Upper Fish River, allocations were based on hypothetical crop combinations which never materialised and which were shown to be inferior to the use irrigators made of the land and water (Backeberg, 1984).

Many authors (e.g. Anderson, 1982; Thobani, 1997; Brisco, 1997; Colby, 1988; Easter and Hearn, 1995) are of the opinion that water markets and market-like arrangements are being used increasingly. As traditional water demands are joined by new demands for environmental quality and the attainment of social/cultural goals, increased social efficiency of water use is needed. In many settings this efficiency is more likely to be achieved through supervised markets than through other institutional arrangements, but the need for market oversight or supervision must not be under emphasized.

Cummings & Nercessiantz (1994) pointed out that as supply and demand conditions change, the efficient allocation of the resource changes. The absence of market institutions to reallocate supplies in response to changing conditions and the importance of goods and services provided by water resources that are not traded and priced in markets, are sources of potential discrepancies in the marginal values of water in alternative uses. A water market is an institution in which water rights are exchanged between willing sellers and willing buyers. Such markets can be formal or informal. Cummings & Nercessiantz (1994) identified two major strengths of water markets:

- Under ideal conditions unfettered markets will result in allocation of water rights that is economically efficient, resulting in water being placed in its highest value uses.
- Water markets can eliminate shortages, lead to efficient pricing and limit distributional conflicts.

Topp and McClintock (1998) pointed out that the introduction and development of water trading could be expected to affect irrigators in two main areas – cash flows and capital flows. On cash flows, one impact of water trading is that irrigators who use less water than their allocation gain from being able to sell unused water. Conversely, irrigators who use more water than their allocation have higher costs because they need to buy additional water. On capital values, making rights to water tradable leads to a separation of the value of water rights from the value of land. Property rights over water become a tradable asset distinct from land, with a value determined by the market. As a result, the value of irrigated land will be lower because it no longer reflects the implicit value of water.

According to Frederick, Van den Berg and Hanson (1996) economic and recreational opportunities and the overall quality of life depend in part on how increasingly scarce water supplies are allocated among competing uses. An economically efficient allocation requires that the marginal value of water is equal in all uses. But the absence of market institutions to reallocate supplies in response to changing conditions and the importance of goods and services provided by water that are not traded and priced in markets, are sources of potential discrepancies in the marginal values of water in alternative uses. Emerging international experience is clear from a conceptual, practical and political perspective; the appropriate approach for ensuring that the scarcity value of water is transmitted to users is to clarify property rights and to facilitate the lease and trading of these rights.

South Africa is a country with limited water resources and very few opportunities of enhancing water supplies economically by building new water works. Such development will also be very costly. Backeberg *et al* (1996) are of the opinion that there is substantial opportunity to ease the pressure of water scarcity by eliminating waste and improving the efficiency of water use. The theory is clear and fairly simple: wherever water is used, it should be done efficiently and without waste. However, attainment of the optimum is much more complicated in practice than in theory. According to Backeberg *et al* (1996) the answer may be a market for water rights, subject to government control and regulation.

2.5 Water as an economic good

There is virtually no substitute for fresh water, whether for basic human survival needs or for economic development. It is not possible to produce paper with milk, or steel with orange juice: both processes need adequate supplies of fresh water, as indeed would the production of milk and the orange juice in the first place. However, almost all economic developments seem to have an associated environmental price tag, and fresh water is perhaps the most sensitive of affected natural resources. Almost all economic activities pollute or otherwise degrade water resources. The users of water therefore create externalities (mostly negative) and thus have a major responsibility regarding the protection, conservation and long-term environmental sustainability of the finite available freshwater resources (Illueca and Rast, 1996).

Users may pay for storing water and for transporting it to where it is used (although sometimes at highly subsidised rates), and also for treatment of the water and disposal of the return flows, but there is rarely any charge to reflect the value of water for a given use, that is, the opportunity costs for putting water to one use at the expense of another (Gibbons, 1986). As a result, few people have incentives to use water efficiently. Policies that underprice water have been much criticised for not promoting efficient use in urban areas and on lands irrigated with water supplied by the government (Wahl, 1989). According to Wahl (1989) urban pricing structures often include such economically inefficient practices as:

- Using average-cost rather than marginal-cost pricing. Marginal-cost pricing is the cost of providing the last increment of water. When the average cost is less than the marginal cost, as in many western cities, pricing at the average cost encourages excess use of water.
- Using decreasing block rates in which the cost of the last units consumed is lower than the cost of initial blocks.
- Recouping a significant fraction of facility costs through property taxes rather than through charges based on water use.
- Failing to meter individual consumers.
- Failing to use seasonal pricing if marginal costs vary by season.

These common practices provide inappropriate price signals to consumers and lead to overuse of water. They also result in over-investment in water-supply facilities relative to investment in other methods of providing or conserving water and relative to expenditure on other goods and services. Anderson (1983) is of the opinion that where farmers must pay prices that reflect the market value of water, there will be greater motivation to use water more efficiently. However, small price increases will likely do little to motivate changes in use if the gap between the price paid and the market price remains large.

Full cost recovery pricing, combined with improved institutional arrangements, have the potential to encourage water use effectiveness and the transfer of water to higher value users. Specific allocations are being set aside for environmental flows. Another solution is to cap certain waterways, restricting the amount of water being taken out of the river system. When water levels decrease, damage can be done to the ecosystem, causing environmental problems (Jones, 1999).

Typical arguments for user-pays are based on the cost of supply without the consideration of the capacity of users to pay. Too little consideration is given to users' willingness to pay in the water pricing debate. If the distribution of water entitlements does not correspond to demand, then the optimal economic value of the resource will never be realised and it is unlikely that licensees will be able to afford a full user-pays regime. Economic theory suggest that, within the bounds of the market constraints necessary to protect existing water entitlements, market prices should reveal the buyers' willingness to pay for incremental increases in water supply, and therefore provide some guidance as to the appropriate level of statutory charges for additional water (Tisdell, 1996).

According to Brisco (1996) there are three important factors pertaining to water as an economic good. They are the use cost of water, the value of water and the opportunity cost of the resource. The interaction between these three critical factors is explored in the next three sections.

2.5.1 The cost of water

Rogers *et al* (1996) are of the opinion that there are several general principles involved in assessing the economic value of water and the cost associated with its provision. According to him there are four important concepts:

- Full supply cost
- Full economic cost

- Full cost
- Value in use

The **full supply cost** includes the cost associated with the supply of water to a consumer without consideration of either externalities imposed upon others or the alternate uses of water. **Full supply costs** are composed of operations and maintenance and of capital charges. The **full economic cost** of water is the sum of the **full supply cost**, the **opportunity cost** associated with the alternate use of the same water resources, and the **economic externalities** imposed upon others due to the consumption of water by a specific actor.

The most common **economic externalities** are those associated with the impact of an upstream diversion of water or pollution on downstream users. There are also externalities due to over-extraction from, or contamination of, common pool resources such as lakes and underground water. There may also be production in irrigated areas damaging the markets for upland non-irrigated agriculture, or forcing them to change their inputs. The standard economic approach to externalities is to define the system in such a way as to internalise the externalities.

Rogers *et al* (1996) however separated externalities into economic and environmental externalities. In either case the externalities can be sub-divided into positive and negative externalities. It is important to characterise the situation in a given context and estimate the positive or negative externalities and adjust the full cost by these impacts.

The **full cost** of consumption of water is the **full economic cost**, given above, plus the **environmental externalities**. These costs have to be determined based upon the damages caused where such data are available or as additional costs of treatment to return the water to its original quality. Environmental externalities are those associated with public health and ecosystem maintenance. If pollution causes increased production or consumption costs to downstream users it is an economic externality, but if it causes public health or ecosystem impacts then it can be defined as an environmental externality.

2.5.2 Value of water

Brisco (1996) defined the value of water to a user as the maximum amount he would be willing to pay for its use. For normal economic goods, which are exchanged between buyers and sellers under a specified set of conditions, this value can be measured by estimating the area under the demand curve.

This section discusses the methodology for estimating the value of water, the most important aspects that influence the value of water and the value of water in alternative uses.

2.5.2.1 Methodologies for estimating the value of water

Gibbons (1986) mentions several methods that are used to estimate the value of water in different end uses. These methods include:

- estimating demand curves and integrating the areas below them;
- examining market-like transactions;
- estimating production functions and simulating the loss of output which would result from the use of one unit less water;
- estimating the costs of providing water if an existing resource were not to be available and
- asking with carefully structured "contingent valuation" questions how much users value the resource.

Gibbons (1986) points out that irrigation values can be either marginal values or average values, crop specific or calculated for a mixture of crops; and they can be long run or shortrun. The basic methodologies for estimating water values are crop-water production function analysis and farm crop budgets analysis, including linear programming. Irrigation water values are heavily dependent on crop prices. In crop budgeting and linear programming analyses, water values are also dependent on non-water input costs. As the prices of other inputs escalate, the estimated value of water declines, as long as crop prices and irrigation efficiencies remain constant. Subsidised inputs lead to distortions and affect the estimated values of irrigation water. The negative indirect results of irrigation include the water quality externalities. To the extent that these negative effects are not incorporated into irrigation water values, the numbers overestimate the true value of water used in irrigation.

In a literature review compiled by Frederick *et al* (1996) nearly 500 water values from 41 different studies were presented for the United States of America. A variety of methods were employed to estimate these water values. Both average and marginal values were estimated, although marginal values are the relevant measure for assessing the efficiency with which water is allocated among alternative uses. Irrigation water values are estimated from both crop-water production functions and farm crop budget studies that use linear programming. In spite of the differences in methodologies used, the primary factors underlying the wide variations in the estimated irrigation water values are the crop grown, the location, and the year of the estimate rather than the methodology employed. For withdrawal water uses such as industrial processing and domestic use, it was found that the value of water tends to be higher than for in-stream uses. Industrial processing and domestic uses are the highest-value uses based on both the average and median figures. However, recreation use, fish and wildlife habitat and irrigation which together account for nearly 80 percent of all the estimates, have the highest individual estimated values. The individual water value estimates in this study were generally based on conditions relevant to specific locations, times and water supply situations. Water values tended to be higher in the drier, water scarcer areas of the country.

2.5.2.2 Important aspects influencing the value of water

Frederick *et al* (1996) identified a number of important aspects in the interpretation of water values:

- Water has a number of dimensions – quantity, quality, timing and location – that influence its value in particular uses. Quantity is the most popular dimension considered in value estimates. Since water uses are subject to diminishing marginal utility, the larger the quantity at any given time, the lower the marginal value.
- Water quality is important for most water uses.
- Timing can have an important influence on a water value. Irrigation water is, for example, more valuable when applied during periods of critical plant growth and when crops are under water stress.

- Water values may vary widely among locations. Relative to its value in most uses, water is expensive to transport out of natural or existing channels. Even within the same basin, allowance should be made for the cost of transporting water from the stream to the site of use when comparing offstream and instream water values.

Michelsen, Booker and Person (2000) argued that water rights are in fact valued as real property, akin to land, housing and other assets. Therefore, the demand for water rights may change due to factors affecting the cost of obtaining them, or the value they carry over time. Anticipated changes in demand, supply, and other factors may influence the price path of water rights. Expectations regarding future population growth, economic growth, inflation and interest rates, regional water supply or changes in institutions can be expected to affect willingness to pay for water.

Brennan and Soccimarro (1999) stated that the **value-in-use** depends crucially on the timing and reliability of the water supplies. Timeliness is most critical in irrigated agriculture where water shortages during critical stages of plant growth result in reduced crop yields. Lack of reliable irrigation supplies in public irrigation systems are responsible for low crop yields and farmers' lack of willingness to pay the full cost of water. Water allocation policies and the associated decisions concerning dam management also vary across jurisdictions.

However, improving reliability and timelines in water supplies entails higher costs in terms of additional storage capacity and/or pumping. These irrigation costs account for as much as 20 percent of the net value of output from these crops and indicate that farmers' willingness-to-pay (as well as actual payments) are quite high for timely and reliable water supplies for irrigation. Hence, those institutional and financing arrangements which ensure reliable water supplies are likely to be more sustainable for improving water use efficiency than those which concentrate only on cost-recovery (Tisdell, 1996).

Brisco (1996) pointed out that reliable and adequate water supplies are also critical for households and industrial users. High investment costs are incurred and households pay high prices as part of the coping strategies adopted in the face of uncertain water supplies. Reliable water supplies for industry and thermal power plants are critical for maintaining desired production levels.

Since water for industrial and power purposes are also required during the dry season, provision of water for these users entails both high opportunity costs and high supply costs. Providing reliable water supplies during dry season result in higher storage costs and higher evaporation losses in reservoirs and canals. These costs have to be taken into account while evaluating the benefits and costs of industrial water supplies. Further, the need to provide a given quantity to industry in dry season may result in lower area under irrigation when their peak water requirements coincide during a particular fortnight. This has to be factored in when calculating the opportunity costs of water in the industrial and urban sectors (Brisco, 1996).

As in the case of reliability, water quality influences both values and costs. The first 3 to 4 litres of water used for drinking purposes has to be of the best quality and provides high value to the consumer as well as to society. Water for bathing, washing and personal hygiene need not be of the same quality as that used for drinking and cooking purposes. Flushing of toilets, cleaning and gardening require varying qualities of water, resulting in differing levels of value and hence willingness to pay. Industrial processes can use recycled water for process, cooling and for transporting waste materials. Similarly agriculture requires differing water qualities, resulting in differing values and costs of providing the water. In particular, the demand for various water qualities for different uses provides incentives for recycling and re-use of water, with a view to matching demands with supplies (Brisco, 1996).

2.5.2.3 Generally accepted guidelines for the value of water in alternative uses

Water is essential for all life; consequently, its total value is infinite. But for purposes of allocating scarce resources efficiently among competing uses, marginal water values (that is, the additional value contributed by the last unit of water to a particular use) are of particular interest.

Conclusions, which emerge in similar studies (Shah, 1993; World Bank, 1995; Gibbons, 1986; Gazmuri and Rosegrant, 1996; Briscoe, 1996; World Bank Water Demand Research Team, 1993) that draw together large amounts of available data, include:

- **Value in irrigated agriculture in industrialised countries**: It is, firstly, important to note that irrigated agriculture accounts for a large proportion of water use, especially in many water-scarce areas. The value of water for many low-value crops (such as food grains and fodder) is universally very low. Where reliable supplies are used on high-value crops, the value of water can be high, sometimes of a order of magnitude similar to the value of water in municipal and industrial end uses.

- **Value of irrigation water in developing countries:** The picture in developing countries is similar. In Western India groundwater is exploited by private farmers and is provided in a timely and responsive fashion to users (the farmers themselves and others to whom they sell the water). The water is used on high-value crops (including fruits, vegetables and flowers). The value of water, as reflected in active and sophisticated water markets, is high. In public (mostly surface) irrigation systems in the same country, the quality of the irrigation supply is poor, foodgrains are the major crop produced, and the value of water is typically only about 0.5 cents per cubic meter, orders of magnitude lower than in the private groundwater schemes. Similar very large and persistent differences are found in publicly run irrigation schemes throughout the developing world (Gibbons, 1986).
- **The value of water for hydropower:** The short-run values for water in hydropower in industrialised countries are typically quite low, often no higher than the value in irrigated agriculture. Long-run values are even lower. Whether hydropower is an economic proposition depends greatly on particulars of the economy, of the power sector and of the water sector. Where water is abundant and there are few competing uses, hydropower is likely to be economically viable; where water is scarce (and therefore competition high), the case for hydropower is less clear-cut. In developing countries the demand for power is growing very rapidly. Although energy conservation is important here (as in industrialised countries), large capacity expansion is inevitable and essential. It has been argued that the high environmental costs of alternatives (especially fossil-fuel based generation) mean that hydropower is a particularly attractive alternative in many developing countries. Interestingly, data suggest that the environmental costs as measured by flooded area per kw and number of oustees per kw are substantially smaller for big dams than smaller dams (less than 100 megawatts of installed capacity). It is frequently argued that hydropower is a non-consumptive use and therefore does not impose costs on others. It is this notion, which has, for instance, been behind the creation of two separate categories of water rights "non-consumptive" and "consumptive" in Chile. What is evident in Chile and elsewhere is that the situation is not this simple. By modifying

flow regimes and the timing of water to downstream users, hydropower installations can impose major costs on other users. The key issue is not consumptive or non-consumptive use, but the costs imposed on others by a particular use of a resource.

- **The value of water for household purposes** is usually much higher than the value for most irrigated crops. Not surprisingly, the value for "basic human needs" and for household uses is much higher than the value for discretionary uses (such as garden watering). An important finding (similar to that emerging from the irrigation data) is that people, even poor people in developing countries, value a reliable supply much more than they value the intermittent, unpredictable supplies which are the norm in most developing countries.
- **The value of water for industrial purposes** is typically of a similar order of magnitude to that of supplies for household purposes.
- **The value for environmental purposes** (such as maintenance of wetlands, wildlife refuges and river flows) also varies widely, but typically falls between the agricultural and municipal values. In developing countries most similar work has been done on the value of mangrove swamps (in El Salvador, Malaysia, Indonesia and Fiji), which are critically dependent on inflows of fresh water. These data, too, show quite high values (primarily due to the off-site impacts on fisheries).

2.5.3 The opportunity cost of water

According to Rogers *et al* (1996) **opportunity cost** addresses the fact that by consuming water, the user is depriving another user of the water. If that user has a higher value for the water, then there are some opportunity costs experienced by society due to the misallocation of resources. The opportunity cost of water is zero only when there is no shortage of water. Ignoring the opportunity costs would undervalue water, lead to failures to invest, and cause serious misallocations of the resource between users. The opportunity cost concept also applies to issues of environmental quality. Beare, Bell and Fisher (1998) stated that seasonal uncertainty affecting both the availability and demand for water increases the average opportunity cost associated with water use over the irrigation season. Furthermore, with uncertainty, the opportunity cost of water use at any point in time will be at least as great as the opportunity cost under conditions of uncertainty. This implies that calculating the value of water on the basis of agronomic gross margins may substantially understate the value of water and associated infrastructure.

Archibald and Renwick (1998) pointed out that producers' willingness to buy and sell water implies that the opportunity cost of using water in agricultural production will be defined by the water market price, net of total transaction costs and the opportunity cost of the water use right in the case of sellers. Producers' profit is maximised when the volume of irrigation water applied to each crop is chosen in such a way that the value of the marginal product of water for each crop equals the market price of water net of transaction costs.

2.6 Characteristics of water demand and water markets

In most capitalistic countries people, prices and markets are expected to balance supply and demand and to allocate scarce resources. When demand increases faster than supply, higher prices provide incentives to use less and produce more. As conditions change, markets enable resources to move from lower to higher-value uses. Market forces, however, have been slow to develop as means of adapting water use to water scarcity. The characteristics of demand, the nature of the resource and the institutions established to control its use help to explain why (Frederick *et al*, 1988).

This section will first discuss the characteristics of urban and agricultural water demand in terms of the factors influencing price elasticity and observed price elasticities recorded in other studies. This is followed by an in depth discussion of the required conditions for water markets to allocate water sufficiently.

2.6.1 Urban water demand characteristics

Brisco (1997) pointed out that urban water supply is a low-volume, high-value use. The supply costs (incurred in financing and operating the abstraction, transmission, treatment and distribution systems) are relatively high while the opportunity costs (imposed on others as a result of use of the water) are quite low. Accordingly, the priority issue for the economic management of urban water supplies relates primarily to the supply cost. In most developing-country situations however, aiming for economic perfection is neither practical nor helpful. Instead, it is imperative that tariffs be set in a way that is understandable, transparent and legitimate and that it forces suppliers to be accountable (and thus produce service efficiently). In the urban water supply sector, this "common-sense" pricing approach will therefore mean:

- focusing on supply costs and
- aiming to increase user charges.

Price elasticity of demand can be used as a way of predicting the consumption response that changes in water tariffs will most likely lead to. According to Eberhard (1995) some of the main factors influencing the price elasticity of water are:

- Nature of use. Different uses of water have different price elasticities, discretionary use (for example, gardening) is expected to have a greater price elasticity than non-discretionary use (for example, cooking).
- Current consumption levels. Consumers using only a basic amount of water will have much lower price elasticities than consumers using large amounts.
- Water bill as proportion of income. Consumers whose water bill represents a high proportion of their income, will have a higher price elasticity for water.
- Rainfall and season. Price elasticities are typically higher in the summer because use includes more outdoor water use (discretionary use), which is more elastic thus making overall use more elastic than in the winter.

The price elasticity of water is defined as the percentage change in quantity demand (water) divided by the percentage change in price (water). No recent measurements of price elasticities for water in Cape Town are available. Although Döckel (1973) made some estimates, the population composition and income distribution has changed to such an extent since 1973 that the elasticities calculated by him are probably not reliable. There is however a substantial amount of literature on other international estimates, which can be instructive. The USA Public Works Association according to DWAF (1991) calculated price elasticities for several urban uses from 1952 to 1972. They found that the median of a wide range of price elasticities were –0.26 for inside residential use and –0.4 for outside residential use.

Howe and Linaweaver (1967) found in-house water use consistently to be price-inelastic (–0.23), while outside use is more elastic (–0.7). A literature review by the Palmer Development Group (2000) provides selected secondary sources of estimated price elasticities for water. Table 2.1 represents a summary of price elasticities calculated by various authors.

The Palmer Development Group (2000) found that approximately one-third of all estimates of urban price elasticities viewed by them are in the range of 0 to -0.3, a further third are in the range of -0.3 to -0.6 and the remaining third smaller than -0.6. Less than one-tenth of the estimates show that demand is elastic (<-1).

Table 2.1 : Price elasticities of demand for water selected secondary sources

Source	Price elasticity		Comment
	Range	Average	
Residential average			
Yepes et al (1995)	-0.5 to -0.7	-0.45	Long run price elasticities
Yepes et al (1995)	-0.1 to -0.36	-0.21	Short run price elasticities
Winpenny (1994)	-0.1 to -0.75	-0.35	Long run price elasticities
Knight and Piesold (1994)	-0.3 to -0.7		Long run price elasticities
Bahl and Linn (1992)	-0.1 to -0.6	-0.5	
Gormon (1980)			Survey of USA studies
Residential in-house			
Yepes et al (1995)		-0.27	Danielson (1979)
Winpenny (1994)	0.0 to -0.1		Boland (1991)
Spies (1991)		-0.26	American Public Works Assoc.
Residential outdoor use			
Yepes et al (1995)		-1.38	Danielson (1979)
Winpenny (1994)	-0.7 to -0.9		Western USA, Boland (1991)
Winpenny (1994)	-1.3 to -1.6		Eastern USA, Boland (1991)
Spies (1991)		-0.4	American Public Works Assoc.
Commercial and institutional			
Winpenny (1994)	-0.2 to -1.8		Individual categories, Boland(1991)
Yepes et al (1995)	-0.17 to -1.33		Individual categories, Lynn (1978)
Yepes et al (1995)	-0.23 to -0.92		Aggregate categories, short and long
Industrial			
Winpenny (1994)	-0.3 to -6.7		Individual categories, Boland (1991)
Winpenny (1994)	-0.5 to -0.8	-0.77	Aggregate categories, Boland (1991)
Yepes et al (1995)	-0.43 to -1.32		Aggregate categories, 7 studies

Source: Palmer Development Group (2000)

Veck and Bill (1999) found that if a 100 percent increase in the price of metered water for residential use in the Thokoza and Alberton regions in South Africa were introduced, water use would be reduced by 17 percent. Table 2.2 gives a summary of the price-elasticity estimates by Veck and Bill (1999).

Table 2.2 : Price elasticity of demand for water in Alberton and Thokoza

Description of group	**Price Elasticity of Demand**		
	Indoors	**Outdoors**	**Total**
Total population of Alberton and Thokoza	-0.13	-0.38	-0.17
Alberton upper income group	-0.14	-0.47	-0.19
Alberton middle income group	-0.12	-0.46	-0.17
Thokoza & Eden park – lower income group	-0.14	-0.19	-0.14
Alberton – upper and middle income group	-0.13	-0.47	-0.18

2.6.2 Agricultural water demand characteristics

It has been shown by Gibbons (1986) that while irrigated land in the United States is but one-seventh of all cropland, it provides more than one-fourth of total crop value. Backeberg *et al* (1996) pointed out that approximately 60 000 commercial farmers, 120 000 permanent workers, and an unknown number of seasonal workers are involved in irrigation farming, which consumes approximately 51 percent of South Africa's water on some 1.3 million ha. It contributes 25 to 30 percent of South Africa's agricultural output.

According to Backeberg *et al* (1996) approximately 12 million ha of land in South Africa is arable. In the absence of irrigation, rainfed crop production can feed approximately 20 to 30 million people whereas South Africa's population numbers about 42 million. Intensive irrigation production can feed an additional 10 to 15 million people, given the present situation. Improved efficiency will be necessary to feed the expected population of 60 million by the year 2010.

According to Tisdell (1996) three distinct demand functions for irrigation water may be recognized, *viz.* the total demand for irrigation water, the demand for allocated water constrained by existing water entitlements, and the demand for transferable water entitlements. The total demand for water is defined as the crop requirement demand for water, which would occur if the irrigators were free to irrigate efficiently without an allocation constraint (excess demand). In reality, prior to trade the ability of farmers to meet the optimal crop water requirements is constrained by the allocation of entitlements. While the level of announced allocation is a supply side phenomenon, the demand for water cannot be equated with aggregate supply alone. Simply equating aggregate supply with the requirements of irrigators assumes that the distribution of water entitlements reflects irrigators' needs. In many instances it is not the total supply of water that is the constraining factor to production, but the distribution of water allocations. The market demand for transferable entitlements stems from irrigators who do not have sufficient allocated water to irrigate their crops fully. In the short term the transferable entitlements market will reflect any misallocation of water entitlements in the basin, and will redistribute allocations to their most profitable use. In the long term, the market for transferable entitlements will operate as an adjustment process responding to seasonal variations in agricultural production and crop prices.

Most irrigation in developing countries is used in the production of food grains. This type of irrigation involves a high-volume, low-value use of water. But there is an important and growing sector of high-value irrigation (often fruits and vegetables). The supply cost of irrigation water is usually modest, but when there is competition with either urban uses or high-value irrigation, opportunity cost is high. From the perspective of treating water as an economic good, the great challenge to irrigated agriculture is to ensure that farmers consider the opportunity costs, and that there are institutional arrangements to facilitate movement of water to higher-valued uses. This is the essence of the appeal of the approach of water markets. The genius of the approach is that it ensures that the user will face the appropriate economic incentives, but de-links these incentives from the tariff, which is set on "common-sense" grounds (Brisco, 1997).

Improvement in irrigation efficiency renders it important from a water management point of view to use water management tools that are fair and will enable policymakers to reach this objective. These tools can only be developed with a thorough understanding of how farmers will react to certain policy changes. Gibbons (1986) used the example of a firm growing only one crop, with fixed acreage in production, to illustrate the basic principles of the demand for irrigation water. The profit maximising farmer employs more of an input as long as its marginal value is greater than its cost. The profit, maximising level of input use is normally less than the yield-maximising level, unless the input is free. Farmers' demand for irrigation water is therefore derived from its use value in crop production. On a one-crop farm, with all other inputs held at constant levels, a farmer faced with water-cost increases could only adapt by using less water. If the restriction on changing nonwater inputs is removed, the farmer on a one-crop farm can adapt to water-cost increases by substituting other inputs for high-cost water, especially inputs such as improved irrigation management or more efficient irrigation systems. Lifting the one-crop and acreage restriction in this simple example, farmers have several additional strategies for adapting to water scarcities or cost increases. First, the variety of a given crop might be changed to one that needs less water or can withstand greater drought. Secondly, the crop mix can be changed to include crops of higher value per unit of water. Third, some acreage can be reverted to dryland farming or rotated out of production entirely.

According to Gibbons (1986) the extent to which farmers react to higher water costs will affect the overall elasticity of demand for irrigation water. In the very short run, with the growing season under way, irrigation water demand is very unresponsive to price changes. Over the longer run, major adjustments in irrigation efficiency, introduction of new crops, and better management are possible. These strategies render the demand for irrigation water much more responsive to changes in the price of water over the medium and the long run.

Beare *et al* (1998) are of the opinion that calculating the value of water on the basis of agronomic gross margins may substantially understate the value of water and associated infrastructure. The demand for water for crop irrigation has a number of important characteristics, such as season, location and quality requirements and effects. While natural stream flows usually peak in early spring and dwindle through the summer, the demand for irrigation water extends throughout the growing season, peaking in the late summer. The most important dimension of irrigation water demand is probably quantity. Between seasons, over the longer run, major adjustments in irrigation efficiency, introduction of new crops, and better management are possible. These strategies make the demand for irrigation water much more responsive to changes in the price of water over the medium run and the long run.

Clark, Menz, Collins and Firth (1986) developed a regional linear programming model for estimating the short run demand for irrigation water and to estimate demand elasticities. Kulshreshtha and Tewari (1991) used farm level linear programming models to estimate arc demand elasticities for water in the South Saskatchewan River region in the Canada. The demand elasticities obtained by the mentioned researchers are shown in Table 2.3.

Table 2.3: Demand elasticity estimates for irrigation water

Dollar per unit	Demand elasticity	Source and method
A$4/ML to A$21/ML	-0.13	Clark *et al* (1986) Regional LP models
A$21/ML to A$42/ML	-0.65	
A$42/ML to A$51/ML	-3.8	
A$52/ML to $58/ML	-14.1	
US$7.60 to 15.80/af	-0.05	Kulshreshtha and Tewari (1991) Farm LP models
US$23.70 to 39.50/af	-0.73	
US$7.60 to 39.5/af	-0.3	
US$47.38 to 79/af	-0.53	
US$7.60 to 79/af	-0.42	
US$79 to 118.45/af	-1.74	
US$126.35 to 189.52/af	-3.09	

It can be concluded from Table 2.3 that the short-term demand elasticities for water is relatively price inelastic in the lower price ranges and becomes more elastic in the higher price range. The demand for irrigation water appears to be price inelastic, and it will remain price inelastic until water costs rise dramatically. It is important to note the role of uncertainty in the elasticity of irrigation water demand.

Gibbons (1986) is of the opinion that although acting rationally in maximizing expected profits, the risk-averse farmer uses more water on a given crop than may be necessary for yield maximisation, and only reluctantly reduces the amount in the face of water cost increases. The risk-averse farmer will also be the last to switch to new technologies and to crops whose successful production and subsequent revenue are subject to uncertainty.

2.6.3 Required conditions for trade

According to Easter et al (1997) the efficient construction of any market requires the existence of three necessary conditions for trading to occur. These conditions are:

- well defined property rights;
- public information on the supply of and the demand for; and
- the physical and legal possibility for trading to take place.

Of these three necessary conditions by far the most important is the existence of well-defined property rights (Brennan and Scoccimarro, 1999). In the case of water, property rights define and limit the rights and duties of their holders relative to one another and to the rest of society to the use of a certain amount of water, which may be defined either volumetrically or in terms of shares of a stream or canal flow. If rights are poorly defined, market processes cannot be relied upon to allocate water resources efficiently. It is a basic responsibility of governments, as far as markets are concerned, to define, allocate and enforce property rights in water. Government policies play a critical role in defining the institutional setting for market operation and provide the basis for market activity by defining, allocating and enforcing water rights.

2.6.3.1 Property rights

Colby (1988) pointed out that water law, by defining the rights and duties of water users relative to one another and to the rest of society, provides a basis for market exchanges. In order for market participants to estimate the value of a water right they must be able to form expectations about the benefits associated with owning the right and the degree to which the right is protected from impairment by others.

Scott and Coustalin (1995) identified six characteristics of property rights:

- duration or performance;
- flexibility;
- exclusivity or specificity;
- quality of title or security;
- transferability or assignability; and
- divisibility.

The fugitive and elusive nature of water can present problems in the establishment, definition and enforcement of property rights, which are the essential foundation of any market allocation mechanism, but they are not such as to "rule out either the possibility or the desirability of using prices and regulated markets to introduce economic incentives to restrain use, encourage conservation, and facilitate reallocation of supplies" (Frederick and Kneese, 1988). In fact, it seems to be possible that "through careful design of both property rights and market limitations, much can be achieved by relying upon market incentives" (Griffin and Boadu, 1992).

Water markets provide an incentive to reduce agricultural water use, just as higher water tariffs and charges do, but with a more favourable distributional outcome for the rural population. An important precondition for water markets is well-defined transferable private property rights to water. These property rights can take the form of licenses to use groundwater from private wells or to use surface water supplied through public irrigation systems. The quantity specified in the water right can be determined according to historical use, perhaps somewhat reduced in the case of groundwater overpumping. Whether such water rights will be traded in a market or not depends mainly on three factors: the buyer's willingness to pay and the seller's water productivity and transport costs (Shiffler, 1996).

The way property rights are defined will structure the incentives and disincentives which members of society face in their decisions regarding water ownership, use and transfer. In order for market participants to estimate the value of a water right, they must be able to form secure expectations about the benefits and costs associated with owning and transferring it and the degree to which it is protected from impairment by others (Colby, 1988). Only on that basis can they make economically rational decisions about water use and transfer. If property rights are not well defined, the consequent uncertainty will reduce the expected value of the rights and the incentive to engage in trading. To produce efficient resource allocation through the market the definition of property rights should satisfy the conditions of specificity, exclusivity, transferability, comprehensiveness and enforceability (Tietenberg, 1989; Saliba and Bush, 1987):

- The rights and duties of water use rights holders, relative to one another and to the rest of society, should be specified and enforced so that they can form secure expectations regarding the benefits stemming from their rights. Conditions that affect the water rights, their transfers, and the duties of their owners should be clearly defined, preferably as a part of the right or in the body of law, which specifies the rights of the owners. The right must be defined in readily understandable terms and be easily measured in the field using practical methods (Simpson, 1994).
- If water markets are to result in efficient water allocation and to produce appropriate price signals, the buyers and sellers, and not third parties, must enjoy all the benefits and bear all the costs associated with owning, using and transferring the water rights.

- Water rights must be easily transferable at low cost through either sale or lease and not be tied to particular sectors, uses, and priorities or to other property.
- Water rights must be described in all their necessary attributes (e.g. the quantity diverted, the timing, and places of diversion, use and return) that generate value and can affect other water users. Evidence from water markets in the western United States suggests that market prices are strongly influenced by specific water right and transaction characteristics (Colby, Crandall and Bush, 1993). On the other hand, since markets operate more efficiently when the commodity being traded is homogeneous, the definition of the right should not be excessively detailed. The more detailed the definition of the property right in water, the greater will be the heterogeneity among them and the transaction costs for potential buyers and sellers, and hence the more difficult it will be to organize a market (Howe *et al*, 1986).
- Water rights holders must be able to capture the benefits associated with water use and transfer decisions. Since rights cannot be perfectly enforced, ownership will always be probabilistic; but when the probability of capturing benefits from a use is low, the owner is less likely to devote the resource to that use (Anderson, 1982). Water rights must be secure from involuntary seizure or encroachment by others, including the state. Enforcement, via a court system or by mutual control, is needed to ensure the validity of water rights. The water right must be registered and recorded to minimise the possibility of dispute over ownership. In order to enforce user rights it must be possible to monitor water use by individual users, detect violations and the legal ability and authority must exist to deal with the violations. Sanctions should represent a credible threat and induce compliance.

Paterson (1987) stated that property rights are in themselves no barrier to the existence of efficient markets in titles, provided that all the legal limitations on title are uniformly and impersonally applied, and provided that expectations are stable. Paterson (1987) is of the opinion that attention to the definition of rights offers enormous opportunities for enhancement of the technical efficiency of water allocation decisions. Better definitions of rights are a precondition to the creation of a more efficient allocative framework, but property rights and efficient markets are mere technical servants of broader social purposes. Politics and administration, as well as courts, will continue to fix the underlying parameters that condition market outcomes.

2.6.3.2 Public information on the exchange of water rights

According to Colby (1988) publicly available information on the supply of and the demand for water rights must include the means to identify willing buyers, sellers and intermediaries or brokers, and the means for entering into enforceable contracts. Hydrological information is also required to permit the right to be defined. Various types of information are essential for rational decision making by water rights holders, for example, on legal and hydrologic characteristics of water rights, and the cost of alternative means of obtaining water. This implies the existence of a good data and monitoring systems.

The irrigating community should be aware of entitlements at the time of the water license sale. The price and amount of water being transferred should also be accessible to the public. This will allow fair trade within the irrigation community. Traders selling or transferring water allocations for personal profit, which will not be used for the benefits of the irrigation community, should be fined accordingly. Water authorities should manage these allocations to prevent water transfer processes falling into the hands of commercial entrepreneurs (Department of Natural Resources and Environment, 1998).

It has been shown by Brill, Hochman and Zilberman (1997) that a reduction in overall water use accompanied by a reformed transferable water rights system may lead to welfare improvement with minimal information requirements.

2.6.3.3 Transaction costs and the physical and legal possibility for trade

Colby (1990) poses the question whether it should be public policy to minimise the cost of transferring water or whether transaction costs can actually facilitate efficient reallocation by accounting for social costs. He argues that transaction costs are incurred in searching for trading partners, ascertaining the characteristics of water commodities, negotiating price and other terms of transfer, and obtaining legal approval for the proposed change in water use, the latter being policy-induced transaction costs (PITC). Transferors incur PITC as they seek to obtain state approval to transfer a water right to a new place and purpose of use. PITC may include attorneys' fees, engineering and hydrologic studies, court costs and fees paid to state agencies.

According to Thobani (1998) clearly defined sets of transfer rules are necessary to permit market transactions to take place between willing buyers and sellers. Transactions should be contingent only upon compliance with a known set of trading rules or transfer criteria. This is a prerequisite for a continuous water market. When the transfer rules are not known with certainty before the economic agents contemplate a transaction and when potential market participants cannot predict during their negotiations whether or not the proposed transaction will be approved, there is no incentive for continuous market-like decision-making. It must, also, be physically possible for the transfers produced through trade to actually occur. The seller must be able to physically move the water to a suitable point or the buyer must be able to take delivery and convey it to the point of intended use. Thobani (1998) stated that this might require easements or the purchase of rights of way across the property of others.

Market transactions occur when both potential buyers and sellers perceive that there are economic gains to be captured by transferring water to a purpose, place or time of use in which it generates higher net returns than under existing use patterns. Transfers occur automatically whenever the net benefits from a reallocation are positive until marginal values are equalised among water users, uses and locations. Trade will continue until all water users are indifferent between buying and selling water rights. According to Colby (1988) three conditions must be satisfied if a market transaction is to take place:

- the seller must receive a price offer that at least equals both the returns foregone as a result of the water rights given up and the transaction and transportation costs borne by him or her;
- the buyer must expect the returns from the purchase to exceed both the price paid to the seller and the transaction and transportation costs borne by him or her;
- for the buyer, the total costs associated with the market acquisition of water rights must be less than the costs of the least expensive alternative water supply source.

Since market transactions are precipitated by the difference in the value of water in alternative uses and locations, which must be large enough to outweigh the costs of obtaining water through the market process, water markets will become active only where and when water is sufficiently scare, and hence valuable. Conversely, water markets are unlikely to become active where many water rights remain unappropriated, where water supply investments continue to be favoured over reallocation, where transportation and transaction costs are very high, or where there are other sources of low-cost water (Colby, 1988).

Coase (1997) pointed out that if the costs of making an exchange are greater than the gains which that exchange would bring, that exchange would not take place, and the greater production that would flow from specialisation would not be realised.

2.6.4 Forms of water trade transactions

Frederick (1998) pointed out that despite the obstacles to overcome with water markets, the impetus to move from lower to higher-value uses is driving some water transfers. One of the principal benefits of water markets is the almost unlimited possibility for water reallocation, with the only real restraint being the ingenuity of the trading parties. Water rights transfers can take a variety of forms, each serving a different operational purpose in a water resource system.

Israel and Lund (1995) pointed out that the choice of the form of water transfer depends on:

- the structure of the market;
- the legal and third party considerations that the transaction must accommodate;
- the definition and characteristics of the water right;
- the transaction costs;
- the characteristics of supply and demand;
- local conditions;
- and, above all, the needs of the parties to the transaction.

The most common forms of water trade are permanent transfers, lease contracts and option contracts.

2.6.4.1 Permanent water sales/transfers

Fredrick (1998) is of the opinion that temporary transfers are particularly useful for adapting to short-run changes attributable to such factors as climate variability. They are less effective in dealing with long-term imbalances between supply and demand resulting from changing demographic and economic factors, social preferences, or climate. At some point, the historical allocation of water becomes sufficiently out of line with current conditions to warrant a permanent transfer of rights. The permanent transfer of title, including all benefits, costs, risks and obligations associated with the right is usually a response to long-term changes in demand and supply conditions which increase the marginal value of water in some uses and decrease it in others. Sales are "the preferred market structure when the goal is to satisfy permanent demand shifts" (Howitt, 1998). The permanent transfer of water rights through sales can be expected to be less frequent than lease contracts.

Sales are common in intersectoral transfers, with irrigated agriculture being the dominant water seller and urban users the principal buyers. In the western United States, for example, while intra-agricultural transfers occur in many areas, water transfers out of agriculture to municipal and industrial uses are the predominant form of market transactions (Saliba and Bush, 1987). In Chile, intra-agricultural water sales, as well as intersectoral sales, are common in many areas (Easter and Hearn, 1995; Rosegrant and Gazmuri, 1994).

It has been shown by Frederick (1998) that the process of resolving the third-party issues associated with the transfer of a long-term shift in water use is often slow, costly and contentious. Proposed transfers face the hurdle of proving the negative, that a change will not harm others. This development stifles the development of markets in permanent water rights.

2.6.4.2 Lease contracts

The leasing of water rights involves the sale of water, but not of the water right. Under a lease, the title to the water right remains with the lessor and at the end of the contract, the right must be returned. Leases are a preferred market response to short-term changes in demand and supply conditions. These operations are commonly referred to as constituting a spot market for water. Water users may find it advantageous to engage in lease contracts for a variety of reasons. The lessor has an opportunity to earn revenue in the temporary trade of surplus water rights while not giving up water rights. Leases are particularly useful when users need to accommodate: a short-term demand for additional water; a long-term but variable demand; any use that has a predictable and fixed life span; a use of uncertain duration, e.g. a farmer facing variable commodity prices; highly variable supplies, e.g. where it is not economical to transport water in periods of sufficient water supply; water users' unwillingness or inability to commit the resources necessary to buy the water right or the desire to limit their ownership of water rights; and unexpected events (Shupe, Weatherford and Checchio, 1989; Saliba and Bush, 1987).

Under a typical lease contract, the lessee pays the owner of the water right (the lessor), generally in periodic instalments, but there can also be an up-front payment to initiate the lease. Lease contracts are often renewable. The length of a lease in irrigation districts is typically a single season, but it can be longer, even several decades. Leases can be, on the other hand, very short, sometimes for only a few hours. In the short run, leases are usually a cheaper source of water than permanent transfers. However, water can and will fluctuate in price, water supplies are only secure until the contract expires. There is also an expense in the constant renewal costs for those who depend on short-term leases, and there is a risk of default, for the lessee has only a contract as protection, not a property right (Scott and Coustalin, 1995).

Scott and Coustalin (1995) are of the opinion that leasing arrangements can accommodate most varying needs. The flexibility of leases makes them an attractive option for many users, and rental or lease markets are often very active, particularly among neighbouring water rights holders in irrigation districts. Leases, often of informal nature, are usually the predominant form of market transactions. In informal markets, most transactions are in the form of short-term leases, because difficulties with contract enforcement impede the permanent transfers of water rights.

In Chile, for example, leasing has been a much more active form of water reallocation than water rights sales. Perhaps the most common transaction is rental or leasing between neighbouring farmers whose water requirements differ through the cropping cycle (Gazmuri, 1994; Rosegrant and Gazmuri, 1994). In California, as well, water marketing is characterised by an emphasis on seasonal spot markets (Howitt, 1998). A particular form of lease is the leasing-back of purchased rights, usually to the original owners and often for a nominal payment, when rights are bought in anticipation of future needs. A lease-back permits the new owner to receive benefits from the water during the holding period. Moreover, in those jurisdictions where a water right can be lost after a period of non-use, it ensures the continued beneficial use of water rights and acts as a protection from forfeiture. Under a conditional lease-back, water rights are generally leased back to the original owner, except in dry years.

Anderson and Snyder (1997) pointed out that water banks are emerging as an important tool for facilitating water transfers. These banks are generally operated by a government entity and serve as intermediaries between buyers and sellers. Water users with excess water may deposit some or all of it in the bank for rental by other users. The bank often sets the price, timing, eligibility of water rights, and eligibility of recipients. Water banks offer several benefits. First, they make trades easier by standardising the transfer process and relaxing regulatory hurdles. Because banks are government-sanctioned and because they set prices, often not allowing profit, they are more politically acceptable than pure markets. Water banks even shun the idea of buying and selling by referring to bank transactions as deposits and withdrawals.

2.6.4.3 Option contracts

Option contracts, also known as contingent or interruptible water markets, are long-term agreements to lease, less commonly to sell, a water right when a given contingency occurs, typically a drought (dry-year option contracts). Many of the benefits of option contracts could be secured from short-term leases without long-term commitment, but leasing could increase participants' income risk and result in higher transaction costs, including investment in delivery systems and measurement costs of assuring compliance (Hamilton, Whittlesey and Halverson, 1989). There are examples of their use in both the United States and in Chile. A typical arrangement, in Chile, involves the payment by a fruit farmer of a pre-negotiated fee to a farmer growing annual crops for an option on water supply in the case of drought (Thobani, 1997).

Option contracts are commonly used to transfer water from irrigated agriculture to non-agricultural users during periods of low stream flow. Dry-year option contracts are an attractive alternative when water users have adequate water supplies in normal years. Such contracts can provide supplies during droughts at a lower cost than purchases or leases. Michelsen and Young (1993) pointed out that the use of option contracts for temporary irrigation water use, in order to provide drought insurance for urban water agencies in northeast Colorado, is economically viable under a wide range of conditions (). Option contracts are particularly attractive because the lessor:

- maintains secure long-term water supplies;

- receives compensation for the option, including that for the income lost when the option is exercised and for the additional complexity introduced in planning business activities;
- and retains access to water during normal supply conditions when the option is not exercised.

For the lessee, the contract provides a means of obtaining additional water supply, under predetermined conditions and at a specified price, whenever a given contingency occurs. Option contracts are complex. This is in part due to the need to address the risk to the lessee that the water right will not be available when the time comes to exercise the option. In part, this is due to the concern of the lessor that the contract limits his or her property rights and may limit the ability to benefit from future transactions, e.g. an opportunity to sell. However, this issue can be addressed by including in the contract the "right of first refusal" which allows the seller to retain the option of selling the water rights before contract termination, but gives the option holder the right to match the offered price (Michelsen and Young, 1993). In addition, to produce the greatest benefits, option contracts require long-term contractual commitments, often up to twenty or more years, a contract length which can present many uncertainties.

Compensation is often adjustable over time to allow for changes in water use, production costs, technology and other market conditions. Various methods of payments can be used, for instance a lump sum, annual payments, or a combination of annual payments with lump sum when the option is exercised. The latter is a particularly attractive alternative, because neither party needs to fully anticipate the number and severity of interruptions over the entire contract period (Hamilton *et al,* 1989). Sellers could be compensated in kind, for example by lower rates for the buyer's production, as in the case of irrigation to hydroelectricity generation transfers, farmers can be compensated by lowering rates for irrigation pumping power.

2.6.5 Advantages of tradable property rights to water

Howe *et al* 1986 identified desirable characteristics for an ideal water allocation system as:

- flexibility in the allocation of water supplies;

- security of tenure for established water users;
- the capacity to confront the water users with the full opportunity cost of water;
- predictability of the outcome of the reallocation process;
- equability and fairness; and
- and the capacity to reflect collective public and social values.

Economic growth and efficiency require a balance between flexibility and security. Although security of tenure can cause a reduction of flexibility, and vice versa, both can be achieved simultaneously as long as users can voluntarily respond to incentives for reallocating water supplies.

2.6.5.1 Improved efficiency of water use

As pressure on water systems continues to increase, the social efficiency of water allocation must receive increasing attention. The days of big dams are over for most of the world because the economic and environmental costs have become too high. Improvements in the social efficiency of allocations of existing supplies are necessary. The allocation strengths of water markets are necessary for this task but public agency involvement as market participants and supervisors is also essential (Howe *et al*, 1986).

Many technical and regulatory possibilities exist for using water more efficiently. Conservation is likely to have greater potential for reducing water use in irrigated agriculture than in cities, given that agriculture uses the largest proportion of available water. Moreover, in the agricultural sector in the Western United States (as well as South Africa), traditional water law has been a powerful disincentive for practising conservation. For example, where the prior-appropriation doctrine is practised, farmers must use the water they have appropriated or they face losing it. Significant savings are available through urban conservation efforts as well, and the rate of demand growth in this sector is much higher than it is for agriculture (Colby, 1988).

According to Howe *et al* (1986) improving the efficiency of agriculture is important not only because of water conservation, but also because the techniques used may increase the yield of the crop. Modern irrigation methods have proven to result in substantial increases in yield. Many developed countries are basing agriculture on advanced surface irrigation, micro-irrigation technologies, sprinkler irrigation etc. for high returns. Water markets will create financial incentives for irrigators and agricultural engineers to develop and implement water saving technologies. The financial incentive will be the surplus water that can be used to either expand irrigation farming, or the possibility of selling the water. Within a centralised system there is a lack of water saving incentives.

Thobani (1995) pointed out that one way to do so is to charge a price for water that reflects its true scarcity. But this is difficult to do in practice, especially for irrigation water, which accounts for the bulk of water use. Irrigation water charges are typically well below the cost of obtaining additional water (its long-run marginal cost) and often below the cost of operating and maintaining the irrigation infrastructure. Raising water charges to the long-run marginal cost would result in prices that would bankrupt many farmers, an option that is usually politically and socially unacceptable. A more realistic way to bring about efficient use is to allow water trading. Some water-scarce countries have adopted this alternative, permitting informal sales of water for a season or permanent sales of property rights to water.

Anderson (1982) stated that a market directly confronts water users with the real ***opportunity cost*** of their use and transfer decisions, and forces them to take this opportunity cost into account. If the owner is to be fully aware of the opportunity costs of his actions, property rights must be transferable. When the owner is not allowed to transfer his resource to another use, he will not consider the full opportunity costs of the other use. Water markets would correct deficiencies in water allocation irrespective of the water pricing policy followed by the authorities. Since water would be priced (in the rights market) at its opportunity cost to the user, it would tend to be efficiently used even if the charges collected by the water authorities failed to cover resource cost in total or at the margin.

Thobani (1995) stated that consideration of the opportunity cost in a water market creates a built-in incentive to conserve water and to put it to the most productive use. For example, if farmers were able to sell their water rights at freely negotiated prices, some might choose to generate extra income by selling any surplus rights to a neighbouring city where the water has a higher value. They can often generate a surplus by using more efficient irrigation techniques or by switching to less water-intensive crops. Thus, a tradable water property rights system can lead to voluntary conservation and increases in the productivity of water without having to increase water charges. In fact, in Chile, water charges fell following the introduction of the tradable water rights regime. The fall occurred because this regime facilitated the transfer to user groups, of the responsibility for carrying out operations and maintenance (O&M) activities and for setting water charges and because users were able to carry out O&M activities at a much lower cost than the government. Despite the lower water charges, the opportunity to sell water ensures that scarce water is not used wastefully (Thobani, 1995).

Thobani (1995) pointed out that the price of property rights to water has little relation to the water charges or tariffs for operation and maintenance activities. To use an analogy from the condominium market, one can think of the price of water rights as the purchase price for the apartment and the water tariff as the condominium fee.

Dinar and Letey (1991) found that under some conditions water markets provide an opportunity to increase profitability. Under no condition does a farmer face lower profitability in the presence of a water market. The urban sector benefits because the water market induces increasing water availability for urban use. Assuming that the water market price reflects the urban sector's willingness to pay, the consumer surplus is higher with a water market than without one. This is particularly true and significant with increasing urban growth and water demands on the one hand and limited and very expensive options for developing new fresh water supplies on the other.

Chan (1989a) points out that in a system with well-defined property rights and competitive markets in which to sell those rights, producers and consumers try to maximise their surplus. The price system, then, induces those self-interested parties to make choices, which are efficient for the point of view of the society as a whole.

2.6.5.2 Tradable water rights lead to sound investment

According to Thobani (1995) tradable water rights can help shift water to higher-value uses in a way that is cheaper and fairer than some of the present alternatives. These alternatives include building expensive new water supply infrastructure, confiscating water from farmers, or substantially raising water charges to force farmers to conserve water and to free up water for higher-value uses, such as for "raw" city water. Although the conveyance infrastructure to transfer traded water must already exist or be built, the cost of building it is often less than that of developing new sources of water. Thobani (1995) used Chile as an example to illustrate this. The city of La Serena in Chile was able to meet its rapidly growing demand for water by purchasing excess water rights from farmers at a lower cost than the alternative of contributing to the construction of the proposed Puclara dam (the construction of the dam has now been postponed indefinitely). Farmers recieved a good price for their water and faced incentives to use more efficient irrigation techniques. Better incentives to conserve water also help control soil salinity, which is caused primarily by overwatering. Therefore, by creating tradable water rights, Chile was able not only to avoid the water conflicts that often arise when governments confiscate water from farmers and divert it to urban domestic consumption, but also to avoid the environmental costs associated with new dam construction and soil salinity (Thobani, 1995).

Farmers also benefit from having more secured water rights and an asset that can be used as collateral for lower-interest loans. Secure water rights are particularly beneficial for small farmers, who have been most vulnerable to reductions in their water allocation over time and who have few other sources of collateral. Thobani (1995) stated that because of their divisibility, water rights give large farmers the possibility of mortgaging only part of their water rights for small loans, rather than their entire land and water holdings.

2.6.5.3 Increased investment and growth

In addition to stimulating growth directly by improving the productivity of water, tradable property rights to water will encourage investment and growth in activities that require assured supplies of large quantities of water. The existence of such rights assures investors that their water rights will not be subordinated to those of other users during times of shortage and that, in fact, they will be able to buy water from those with a less valuable use for it. Thus, Chile's 1981 water code allowed investment in fruit production to proceed rapidly, and helped transform Chile into a major fruit exporter (Gazmuri, 1995).

Tradable rights should also stimulate private investment in new water supply projects. The secure rights will give potential investors the confidence that, once they obtain the rights to the water generated by their investment (for example, storage reservoirs and conveyance infrastructure), it will be theirs to keep or to sell to others (farmers, industry, hydropower and water companies). Secure rights to water could also attract private investment to large public water supply projects under construction, enabling them to be completed faster and more cheaply. Public projects tend to run into enormous delays and cost overruns because governments run out of money and because there is less incentive than in private projects to control costs. If a government wanted to privatise an ongoing project, it could do so by selling the hydraulic infrastructure and unallocated water and land rights associated with the project, but with the condition that the buyer respect existing land and water rights (Thobani, 1995).

Anderson and Snyder (1997) are of the opinion that water markets will motivate farmers to cut their consumption and this will free up irrigation water for municipal and other uses. This will reduce the demand to build costly supply projects and delivery systems and would encourage private, profit-making firms to enter the water supply industry, taking the burden of the public treasury.

Markets require ***security*** of tenure, which in turn helps encourage efficient use, resource conservation and capital investment. Security of tenure of water can also help strengthen and consolidate the autonomy of water users' organisations. Security of tenure and the possibility to acquire water rights in the market encourage investment and growth in activities that require secure water supplies (Thobani, 1995).

2.6.5.4 Flexibility

Water markets are flexible because they are by their very nature a decentralised and incentive oriented institution, rather than centralised and regulatory. Transferability of water rights in the market provides the freedom to reallocate water as economic, social and environmental demands and conditions change. "In a dynamic society with continually changing values, it is this transferability which insures flexibility. Entrepreneurs continually have new and better ideas of how to utilise resources. It is their offers to buy and sell these resources that generate progress. If transferability is not allowed, there is no effective way for the system to respond to changes in demand and supply" (Anderson, 1985).

With transferable water rights, marginal values for water, net of transaction and conveyance costs, are equated across water users, uses and locations. The equalisation occurs because the market provides both an incentive and a means for water users to reallocate water rights to higher-value uses and users whenever reallocation would generate positive net benefits. The transferability of water rights in the market enables new uses and users to emerge and obtain water supplies, and prevents waste and encourages water conservation. It also provides a continuous incentive for adoption, research and development of superior water utilisation, conservation and production technologies. A market-based system of water allocation will be both resilient to shocks and open to take advantage of opportunities (Anderson, 1985).

According to the U.S. Office of Technology (1993) properly implemented water markets and transfers can serve to reallocate water quickly and efficiently under current climatic conditions. Marketing arrangements can vary from permanent sales of water to short-term, seasonal, or dry-year agreements. Each of these types of reallocation could also serve to provide more-efficient and flexible use of water in the event of the number, duration or intensity of extreme events increases. The U.S. Office of Technology (1993) is of the opinion that severe drought conditions in the Western United States between 1987 and 1992 may offer a glimpse of what problems a future, drier region could encounter and of some of the measures that might be taken in response. Approaches similar to California's Drought Water Bank are likely to be useful in other regions and could eventually become permanent institutions. Such sales of water to higher-value uses would ensure that as much economic productivity is maintained in a region as possible.

Hamilton *et al* (1989) pointed at an additional characteristic of water markets in that they do not inherently require long lead times to establish, such as are required of new dams. California's Drought Water Bank, for example, although not without problems and not a full-fledged market, was implemented in a few months. Water markets and market-like transfers may allow society to delay or avoid more-costly or less-flexible adaptation options.

The American experience shows that the promotion of interstate, as well as intrastate, transfers could help make management of water resources more flexible and efficient, especially where infrastructure for transferring the water already exists. Such transfers, for example, could be useful in the Colorado River Basin. Without some vehicle for transmitting price signals across state borders, low-value irrigation uses in the Upper Basin states have the potential to displace high-value urban uses in the Lower Basin, where water may have 10 times the value (Colby *et al*, 1993).

2.6.5.5 Ability to gather, process and use information

According to Anderson (1985) the principal advantage of a market is the ability to gather, process and use information effectively, an ability that is irreplaceable. Demand and supply conditions change continuously, and this information is fragmented and dispersed among all actual and potential water users and is both time and place specific with a high variance across localised ecosystems. If public authorities had the information necessary to make trade-offs between users, including information about the value of water in all alternative uses, and demand and supply conditions for every user, regulatory policies could be determined to ensure efficient resource allocation. Given that public authorities cannot acquire such information at a reasonable cost, non-tradable water rights systems cannot achieve economic efficiency and equity, and are likely to result in the allocation, which is rigid over time and unresponsive to changing social values (Howe, 1996a). "There is no way that a well-intentioned bureaucrat can know what constitutes a beneficial use without market transactions. It is the trading of well-defined and enforced property rights which will enable individuals with the knowledge of the particular circumstances of time and place to co-ordinate their knowledge and make sensible water use decisions" (Anderson, 1985).

Cummings and Nercissiantz (1994) are of the opinion that a continuous trade in water rights generates prices that by coordinating dispersed information and preferences indicate the opportunity cost of water or its relative scarcity. Price is an information-rich signal which summarises all information available to market participants and motivates appropriate levels of individual action in response to changing demand and supply conditions, thus performing the crucial rationing function in allocating resources to different uses and users. Thus, transferable water rights create a system of economic incentives in which those who have the best knowledge about returns to water in their intended use can benefit from the system. Water users themselves are encouraged to use that knowledge to allocate water to higher-value uses and hence maximise the economic value obtained from the scarce resource with a minimum of bureaucratic apparatus. Obviously, the extent to which observed market prices accurately measure the scarcity value of water and encourage its efficient allocation, will depend upon the extent to which the characteristics of the market approximate those of the competitive paradigm.

2.6.5.6 Water markets are fair

According to Anderson (1985) water market transactions are fair in the sense that water reallocation takes place through voluntary mutually beneficial trades with perceived advantages for all the parties involved; each party must be made better off or one would refrain from trading. Markets can guarantee fairness only, however, if no single market participant can affect market prices. In addition, unless conducted in an institutional framework which causes market participants to take into account third party impacts, markets generally cannot guarantee fairness to third parties that may be negatively affected by market transactions.

Scott and Coustalin (1995) pointed out that since the future prices in water transfers and the equilibrium allocation are unknown when a decision is made to introduce water rights transferability, the distributional implications cannot be known beforehand. On the whole, there is no particular reason to expect that a water market will necessarily result in an ***equitable*** allocation of water resources or change income distribution in any particular way. If equity and other important ***collective, public or social values*** related to water use are an important part of water policies, it may be necessary to opt for a degree of governmental regulation. Purchasing water rights or reserving them in the initial allocation of rights can usually accommodate these concerns within the logic of the market system. On the other hand, concerns about equity should probably be treated outside the market, though ultimately and in the long run they are interrelated. The problem is income distribution, not the mechanism for water allocation. On the whole, water marketing is unlikely to create new problems of unequal or unfair distribution beyond the reach of government policy (Scott and Coustalin, 1995).

Howe (1990) argued that water markets possess a number of desirable characteristics for efficient allocation of resources. Markets guarantee flexibility in allocation while providing security of tenure (no one has to sell). The price established in the market and the ability to sell at that price if desired force the decision maker to take the resource opportunity cost into account. Markets guarantee fairness between buyer and seller, by definition, since each must be made better off or one would refrain from trading.

Finally, although theoretically, some goals for water allocation, such as predictability, equity and fairness, and the need to reflect collective, public or social values, might be better served by non-market institutions. The existence of these problems does not necessary call for a non-market alternative (Anderson, 1982). "Market failure" in some abstract sense does not mean that a non-market alternative will not also fail in the same or in some other abstract sense (Castle, 1965).

2.6.6 Imperfections of water markets

Water systems always involve interdependency. The withdrawals and consumption of one user, and the changes it causes in water quality, affect others. Externalities are pervasive. Thus a market system in water rights cannot perform efficiently without some kind of supervision. The "no injury rule" - avoiding damage to other users when water is first appropriated or later traded - must be enforced by a supervisory agency. But even when other water users are protected from injury, there remains a range of increasingly important social values that will not be protected or adequately taken into account by supervised water markets as we now know them (Brennan and Scoccimarro, 1999).

According to Chan (1989b) the market has its place in society, but society needs to keep the market in its place. To permit the operation of the market in apparent total disregard for the special needs and requirements of various regions in an area, which arouse such intense anxiety as water, seems unwise. A regulatory policy based on equitable apportionment might be better suited to achieve the objectives of equity, freedom, and community cohesion as it treats the rights of each region on an equal basis, specifies the share of regional water each region is entitled to, and thus enables each region to plan and manage its water resources to fulfil its own aspirations.

While the potential benefits of water trade are well recognised (Randall, 1981; Howe *et al*, 1986), the potential costs associated with changing the spatial location of water consumption are often ignored in the policy arena. The common property nature of water in the delivery system, and the difficulty in clearly defining rights to use, imply that such water trades can affect third parties. Further, the public good characteristics of some water uses imply that parties affected by water trades may not always be well represented in the market. The benefits of improving water resource use through market allocation methods will depend on how these issues are dealt with when designing tradable water entitlements.

While market transactions guarantee security of tenure to buyers and sellers, the rights of third parties are vulnerable to externalities from water transfers. If water users do not face all the costs and benefits associated with their decisions, then their decisions may be beneficial to them even though they are actually inefficient from an overall social perspective. Thus, to ensure that market transfers do indeed produce net social benefits, water marketing must be conducted in an institutional framework, which causes the buyers and the sellers to take account of third party impacts without unduly restricting water transferability (Saliba and Bush, 1987).

Table 2.4 shows the restrictions and effects of restrictions in water markets. Even where water markets exist, the State must be involved in a regulatory capacity.

Table 2.4 : Restrictions in water markets

Restrictions	**Effects**
Imperfect competition and market restrictions	Market participants or public agencies restrict price levels and other conditions of market transfer, and observed prices may reflect these restrictions
External effects of market activities	Market prices do not take into account the values of parties external to the price negotiation process or impacts of transfers on third parties.
Uncertainty	Uncertainty regarding future water supplies, demand, and the legal framework that governs water transfers will affect market decisions and observed prices.
Equity and conflict resolution	Economic and legal barriers to market participation can create inequitable access to water. Water allocation decisions may serve as a form of conflict resolution and be made on political rather than economic grounds. Market prices may not fully reflect these considerations.

Source: Saliba and Bush (1987).

Firstly, private transactions in water or water rights hardly take place under conditions of pure or perfect competition. There are possibilities of monopolisation and/or coercion, and these have to be regulated by the State. Secondly, the state has a duty to see to it that the poor get water for their needs and enjoyment (Backeberg *et al*, 1996).

Despite the advantages of water reallocation, the possibility that water transfers could adversely affect parties not directly involved in them has left some people wary. Smith (1988) listed a couple of issues that often arise: What review process or standard should be used to balance the benefits to farmers from water trades against the secondary economic effects on the local community? What are the obstacles facing a sale or trade when farmers receive their water from an irrigation district or pursuant to a contract with a government water project? How will transactions cope with surface-water return flows and ground water recharge? Who protects fresh-water fisheries, recreational white water and other ecologic and aesthetic values of rivers?

The National Research Council (1992) pointed out that some states in the United States have taken steps to modify their water codes to address these issues, but state water codes are not uniform and not equally conducive to transfers. Water transfers have a controversial history to overcome. The earliest water transfers often took place without adequate consideration of equity, regional economics, the environment, or areas of origin. Water transfers have sometimes been referred to as "water grabs" because gains to the receiving water users have often come at the expense of a loss of water security and opportunity for water users in the area of origin. National Research Council (1992) regards the Owens Valley of Eastern California as the classic example where early this century agents from the City of Los Angeles made several disguised purchases of land for the purpose of diverting the associated water hundreds of miles to the south. The economic and environmental impact on Owens Valley was devastating, and the Valley has never recovered. Transfers do not necessarily result in losses. As experience is gained with transfer mechanisms and states ensure protection of third-party interests, some current concerns should be allayed.

According to Frederick *et al* (1996) efficient markets require that buyers and sellers bear the full costs and benefits of transfers. But interdependencies among the many users of a stream or aquifer make that difficult to achieve. Selling water rights, for example, is likely to alter the quantity of water in a stream, or the location of a diversion or returnflow. Third parties (people benefiting from the water other than the buyer and seller) will be affected by the change. Third-party impacts could include a change in the recreational amenities provided by a free-flowing stream or the erosion of a rural community's tax base when a farmer sells water to a city. Efficient markets also require well-defined, transferable property rights. But riparian rights, which are still the principal basis of water law in many countries, are poorly defined because water use is subject to regulatory or judicial interpretations as to what is reasonable or might unduly inconvenience others. Moreover, these rights are not directly marketable because they are attached and their use is restricted to the lands adjacent to a stream. In the Western United States, where streams are less common and flows are smaller and less reliable, prior appropriation quickly displaced riparian rights as the primary basis of water law. Appropriative rights are established by withdrawing water from its natural source and putting it to beneficial use. During drought, supplies are allocated according to the principle of "first in time, first in right". This principle provided a powerful incentive for the quick diversion of streamflows and allowed irrigators to acquire the highest priority rights to much of the water; while appropriative rights can be transferable, they are commonly attenuated in ways that limit how and where water can be used.

In recent decades, environmental laws have been used to block construction of many dams and in some cases to challenge previously established rights to divert water from streams and lakes. Domestic, industrial and agricultural users continue to compete for water that is withdrawn from reservoirs and streams, and now all three groups must also compete with environmentalists and recreationalists over how much water may be diverted. Conflicts also arise over the priority that dam managers should give to flood control, water supplies, hydropower production, fish habitat, and recreational opportunities. These conflicts are now generally played out in the courts or administrative proceedings rather than in the marketplace (Frederick *et al*, 1996).

According to Bauer (1996) pro-market policies have both strengths and weaknesses in different areas of water management. At their best they implement the fourth Dublin Principle, that water is an economic good with economic value. Such policies can raise economic efficiency through financial incentives and flexible reallocation of resources, which are most likely to be effective at the local scale and involving the same types of water use. They can also facilitate long-term trends in regional economic development, such as growing urbanisation at the expense of agriculture, although this is often politically controversial as well. They may bring environmental benefits as advocated in Principle 1: "increasing the efficiency of use may remove the need for new projects or make more water available for ecological purposes, such as in-stream flow". How ecological purposes are paid for in a market system remains a hard question.

Bauer's (1996) view is that market mechanisms are incapable of handling broader problems of multiple water use, environmental and third-party effects, river basin management, or conflict resolution. These problems are in many ways the core of the Dublin Principles, exactly the types of problems that the International Conference was organised to address. It is here that environmental sustainability and social participation meet water's economic values in all its competing uses. Such problems are both theoretically and practically very difficult: they can rarely be solved by a simple exchange of rights, and when private bargaining breaks down they highlight the importance of wider legal and political institutions. In this way the Dublin Principles support a balanced and moderate approach to water markets, to take advantage of their potential benefits while recognising their constraints.

Brennan and Scoccimarro (1999) pointed out that another feature of water delivery systems that would need attention in a market-based system is the jointness of infrastructure. Most of the costs associated with this infrastructure, including the costs of maintenance and replacement of structures and, in many systems, the costs of water lost in wetting the delivery channels, are not use-related. Any reduction in the volume of water delivered through a particular system will raise the average costs of the water delivery infrastructure for the remaining irrigators; however, a range of possible pricing mechanisms for joint cost recovery are possible. In South Australia, purchasers of water from government irrigation areas must pay a levy of approximately $7.50/megalitre per year (Challen and Petch, 1997). This effects a "compensation payment" to users in the area of origin (maintaining the existing revenue base for infrastructure maintenance) and promotes pricing signals that discourage movements of water out of the region. While this creates an imbalance in water resource use at the margin, the lumpiness in investment decisions for water delivery structure implies that such pricing mechanisms will not necessarily be sub-optimal over the longer term.

The problems associated with pricing and investments in irrigation infrastructure are important issues in a market setting, especially given the depreciated state of most current irrigation infrastructure. Miller (1987) argues that the common practice of restricting trade outside local irrigation areas in the United States may be a jointly optimal arrangement, because of the impact on water delivery infrastructure. Rosegrant (1995) reports that the restrictions on water trade (which, in California, is limited to about 20 percent of consumptive use rights) are also driven by political and social concerns relating to the impact on regional economies.

It is important that proponents of water markets recognise the other costs associated with trade on such markets when determining the gains from expanding existing water markets.

Challen and Petch (1997) provide evidence to suggest that thin trading on the South Australian water market has resulted in significant market price dispersion, indicating that the reliance on markets to allocate water efficiently may have been overstated. These costs, together with the potential for errors in designing rights to protect third parties, may imply that the net benefits of market allocation methods for water are significantly reduced.

Despite the imperfections associated with a water market allocation approach, water markets are still preferred by most authors above central allocation. Water resource development and management therefore should be delegated to those concerned or affected, and should be integrated with all sectoral demands. These may be existing bodies, institutions and mechanisms or special river basin authorities. Consistent with such institutional structures is a greater reliance on incentives, prices and markets and less reliance on traditional command and control approaches. There is no example in the world of a totally free market system with no imperfections. There are however many of examples of well-functioning water markets with moderate intervention through central planning (California, Chilli, Australia). One matter is clear, water users respond to incentives, and when water becomes more expensive, they conserve and use it more efficiently without much effect on overall welfare. The problem is not so much a water scarcity crisis but rather a water management crisis.

According to Anderson (1982) the existence of market failure does not necessarily call for a nonmarket alternative. The relevant comparison is between imperfect market solutions and imperfect bureaucratic solutions. The next section discusses the practical considerations when water markets are established and policy measures to overcome market imperfections.

2.7 Establishing water markets and overcoming market imperfections

Griffin and Hsun Hsu (1993) pointed out that water marketing cannot efficiently allocate both diverted and instream water unless the market is administered in a particular fashion. The focus should be on the development of a property rights system that can serve as an interface among water diverters and instream flow users. According to Griffin and Hsun Hsu (1993) water marketing is capable of promoting Pareto optimality if the following elements are included in market design:

- Transferable diversion and consumption rights must be established. These rights can be exchanged independently or together.
- Return flow coefficients must be established to identify where each diverter's return flow re-enters the water body. This information is required for every diverter engaged in water marketing.
- An institutional mechanism such as Water Districts or administratively established economic incentives is needed to establish market presence for those individuals with preferences concerning instream flows.

According to them these are the three fundamental components of an efficient system for water marketing. The primary reason is that market transfers among diverters will continue to neglect instream water values in the absence of the third fundamental component above.

2.7.1 Implementation of water markets

Thobani (1998) identified useful guidelines in the establishment of water markets. The following actions are necessary:

- Conduct an information campaign to explain to users how formal property rights for water can help make their rights more secure and how trading can result in mutual gains.
- Register rights of existing users without charge based on their historic usage. There may also be merit in trying to partially rectify some of the most egregious wrongs. However, if the government were to try to use this opportunity to correct all such mistakes or to confiscate all illegally obtained rights, there is a good chance that the legislation will be blocked and the injustices will continue.
- Assign new rights via auction. Prior to any auction the government should verify that the water is not being used by others and that it is not needed for environmental or recreational purposes. The government needs to reserve water rights for such instream uses. Any costs to enter the auction should be kept as low as possible.
- Protect water rights of third parties. Even if the initial allocation procedures ensure that the water rights of existing users are protected, subsequent sales could infringe upon the water rights of third parties. This is because of the return flow problem.

One way to solve this problem would be to specify that all water rights have both a consumptive and a non-consumptive portion. While the consumptive portion can be sold without restriction, the non-consumptive part can be sold only if it does not deprive other water users.

- Protect against monopolies through taxes and regulations.
- Protect against water pollution and aquifer depletion.

According to Hearne and Easter (1997) the effectiveness of water markets is constrained by the ability of buyers and sellers to measure and transport water, to legalise and enforce transactions, and to account for water quality. Thus, the effect of transaction costs and the infrastructure and institutions that reduce these transaction costs are critical to the effectiveness of water markets.

Kaiser (1998) identified a number of legal, institutional and technical factors which will determine successful water marketing:

- The increasing demand for water driven by population growth and environmental needs.
- The limited availability of alternative supplies.
- Undervalued water sources.
- A critical mass of buyers and sellers.
- Available water information.
- Reasonable transaction cost.
- Defined and enforceable rights to water.
- Minimal transfer restrictions.
- Public interest reviews.
- A conveyance system.
- Institutional promotion.

Kaiser (1998) is of the opinion that when these conditions are present water marketing transfers will occur.

Water resources management should be actively adaptive, i.e. it should seek to learn from experience. If surprise outcomes are expected, initial market trading should probably be conducted at a scale and under regulatory supervision to minimise the chance of irreversible, adverse outcomes (Young, 1986). In this view, a slow evolutionary process can be an advantage rather than a disadvantage. The initial steps should obviously be consistent with the final design of the system. Starting small gives both the institutions and the parties a chance to adjust and to become familiar with the system. Since most initial efforts will be precedent setting, it will take time to work them out. Once the precedents have been established, however, the process will become smoother, quicker and better able to handle a larger number of participants and trades (Tietenberg, 1989). The experience in Chile suggests, however, that by their nature water markets may evolve very slowly and this concern may not, therefore, translate into reality.

2.7.2 Overcoming market imperfections

Most of the market imperfections and the policy issues being raised are not peculiar to a water system based on tradable rights. All water systems must deal with them. Water rights need to be assigned and enforced even under an administered system, and the conveyance infrastructure still must be built. But a market system increases the value of water, so there are more incentives to clearly define water rights, to improve measurement and enforcement, and to establish an efficient mechanism to resolve disputes. Similarly, the same environmental laws and institutions needed to enforce environmental quality under an administered regime can operate under a tradable water rights regime. Moreover, water user associations, which can play a useful role under either an administered allocation system or a water market regime, are more likely to be established or strengthened if water rights are well defined and transferable (Thobani, 1995).

2.7.2.1 The role of the public sector

According to Thobani (1995) water has several unique characteristics that present special challenges for policymakers designing a framework for a well-functioning market in water rights. The issues relate to:

- defining water rights when water flows are variable;

- measuring water;
- enforcing contracts;
- building the necessary infrastructure to transport water;
- minimising damage to third parties;
- protecting against environmental degradation; and
- avoiding monopolistic pricing practices.

A market for water rights will not lead to adequate investment in some potentially high-return activities (flood control, drainage, prevention of soil erosion, siltation reduction) that by their nature are not profitable for a private investor (Thobani, 1995).

Young (1986) is of the opinion that appropriately formulated laws, regulations and taxes can best address market imperfections. For example, difficulties in defining water rights in the face of variable water supply can be handled by defining water rights as a percentage of stream flow (as in Chile) or by specifying different classes of rights (as in Colorado). Similarly, defining water rights suitably or implementing appropriate legislation can help reduce negative hydrological effects on third parties that could occur when water is transferred to other activities.

Aihoon, Groenewald and Sartorious von Bach (1995) proposed pollution insurance to minimise pollution. Government intervention can assist the creation of a formal market for pollution risks. Insurance agencies could be authorised to offer this service. The market mechanism created could be legitimised and protected with the necessary legislature, involving enforceable standards for pollutants and environmental control agencies to monitor and control the system. The control agencies should be able to bring cases in court against the insurers when a client has polluted the environment beyond the level allowed by the standard.

Young (1986) stated that under a tradable water rights system, the public sector's role in the construction, operation and maintenance of water supply infrastructure could be reduced to financing selected high-return activities with strong positive externalities or public goods characteristics. The market, not the government, will determine the allocation and pattern of water use and the prices charged for water rights. Water user associations will determine water charges for operations and maintenance. But there is an important role for government in formulating laws and regulations to establish tradable property rights to water. Young (1986) is of the opinion that the design and implementation of this legislation should pay particular attention to the initial allocation of water rights, dispute resolution mechanisms, creation and maintenance of a water rights registry, and the minimising of negative hydrological third-party effects. Public authorities will also need to design and enforce environmental laws. This approach has the potential to increase the productivity of water use, improve operations and maintenance, stimulate private investment and economic growth, reduce water conflicts, rationalise ongoing and future irrigation development, and free up government resources for activities that have a public good content or positive externalities. And it is likely to especially benefit the poor and to help conserve natural resources

Colby (1990) argued that policy induced transaction costs (PITC) force consideration for externalities that would otherwise be ignored by water buyers and sellers negotiating in their own best interest; he concluded that PITC may have a legitimate role in promoting efficient water use. For PITC to facilitate efficient water allocation, they would have to provide incentives such that water reallocation occurs if and only if the social benefits of transferring water exceed the social cost. Social welfare is maximised when water transfers occur to the point where the marginal social benefits of transferring one unit of water equal the marginal social costs. Given the public good nature of water and pervasive externalities associated with water transfer, the private marginal costs of water transfers are likely to diverge from the social marginal costs. Transaction costs could promote efficient allocation if they behaved like a tax, causing private decision makers to account for social costs by "taxing" transferors through PITC. Colby (1990) is of the opinion that PITC should be high in areas where new water supplies are locally unavailable and expensive to import, demand for water is increasing and water rights are valuable property. High PITC reflects the substantial and multiple economic benefits associated with water in various uses, benefits that can be impaired by a transfer. PITC should be lower in areas where unclaimed water is still available, there is less pressure for transfers and water rights are lower in value.

Dinar and Letey (1991) pointed out that instead of introducing taxes and regulations, water markets can, under a variety of conditions, enable the farmer to both invest in an improved technology and pay for the safe disposal of drainage produced on his fields. Other social benefits include the reduction in environmental pollution and benefits to the urban sector from additional water for consumption. Following Dinar and Letey (1991) the environment is enhanced by water marketing in two ways. First, the water market induces a shift in irrigation technology and water management, leading to low volumes of deep percolation. Second, with a water market the farmer can afford to pay relatively high costs for the disposal of drainage waters and still maintain his profit margin compared to the non-market case.

2.7.2.2 Initial allocation and definition of water rights

How the initial property rights to water are allocated is crucial to the acceptance and success of a water market. The approach will vary according to the country. Where there is already a well-functioning registry of water rights, it is sufficient to simply reregister the rights in a newly created property rights register. Where the existing registry contains many overlapping property rights (the sum of water rights exceeds the water available), however, it would be better to base the initial allocation on past usage. Where there are gross abuses of water rights, it is probably best to assign rights on the basis of need or with a reasonable upper limit on irrigation water per hectare. In all cases, it is important to ensure that the rights of the poor are respected (Thobani, 1995).

For the most part, there is little danger of widespread monopolies in consumptive water rights. Monopolies could occur, however, following privatisation of water projects with large amounts of unallocated water rights or in non-consumptive water rights for hydropower. To avoid this risk, countries should develop an appropriate regulatory framework before privatising any large water supply infrastructure, introduce a tax on water rights holdings while simultaneously removing any land tax surcharges on irrigated land, and establish regulations determining power tariffs (Young, 1986).

Some of the localised externality problems created by poorly defined rights to drainage water could be improved by specifying rights to consumptive use and creating a market in the return flows (Randall, 1981). However, at a practical level, the enforcement of consumptive use can involve additional costs over a diversion right. If consumptive use were to be enforced by metering, it would require metering the diversion at the farm intake channel and the return flow in the drainage channel. This would not only double the cost of metering, but measurement of drainage would be prone to errors due to rainfall run-off and seepage from other areas. However, not all third party effects can be solved by redefining rights as consumptive use and effecting a market in return flows. This is because the return flows can provide localised in-stream (public good) uses. Where these are important, it might be possible to set minimum and maximum flow targets along particular reaches, which would represent a standard against which trade permits could be issued.

2.7.2.3 Learn from experience in other markets

Important lessons can be learned from the experience in overseas markets. The reliance on judicial procedures to protect the interests of third parties has been a serious impediment to trade in some areas of the United States (Ditwiler, 1975; Young, 1986). However, the degree to which water transactions are caught up in the judicial system varies between states, as do transactions costs, which have been estimated to range between 2 and 20 percent of the value of water (Colby, 1990; Hearne and Easter, 1997). The use of case-by-case determination of water trading permits, e.g. as used in California (Rosegrant, 1995) can be compared with more liberal water trading policies adopted in other states, which incorporate simple transfer rules aimed at protecting third parties whilst reducing "policy-induced" transactions costs. In New Mexico, for example, transferable water quantities are determined utilising standard formulae together with historical and secondary data (Rosegrant and Gazmuri, 1994). Similarly, in Wyoming the state authorities approve temporary transfers on the presumption that 50 per cent of diverted water is consumptively used, and is therefore available for trade.

2.8 The effect of intersectoral water transfers

Easter *et al* (1998) are of the opinion that with the high costs of development limiting the expansion of water supply, the rapidly growing household and industrial demand for water will need to be increasingly met from water savings from agriculture. It will be a particular difficult challenge to improve the efficiency of agricultural water use to maintain crop yields and output growth while at the same time allowing reallocation of water from agriculture to rapidly growing urban and industrial uses. How this will be managed could determine the world's ability to feed itself.

According to the U.S. Office of Technology Assessment (1993) water has very different costs depending on its use; it typically has the lowest value in those sectors that consume the most of it. The disparity between the relatively high prices paid by urban entities and the low prices paid by agricultural users suggest that opportunities exist to use markets to allow more efficient allocation of water. However, the lack of institutional and legal mechanisms for facilitating markets has so far limited their development.

Frederick *et al* (1996) argue that water has been slow to be bought and sold like other commodities but the incentives to do so are very strong. Most of the senior water rights in the arid and semi-arid Western United States are held by farmers and irrigation districts. They pay nothing for the water itself and generally only a modest amount to have it delivered to their farms. As a result, enormous amounts of water are applied liberally to relatively low-value crops and the marginal value of the water is likely to be relatively low. In some cases simply leaving more in the river to provide hydropower, fish and wildlife habitat and recreation rather than diverting it for irrigation could increase the value of the water. In many other instances, the value of water would rise by selling some of it to urban areas that are spending more than ten times as much to augment supplies through recycling or other costly water projects.

Frederick *et al* (1996) pointed out that despite the obstacles, the impetus to move from lower to higher value use is driving some water transfers. Temporary transfers are becoming increasingly common to respond to short-term fluctuations in supply and demand. Precisely because they are temporary short-term leases, options to purchase during dry periods and one-time purchases through water banks blunt a principal third-party concern that a transfer will permanently undermine the economic and social viability of the water-exporting area. Transfers among farmers within the same irrigation district are common and relatively easy to arrange because the third-party impacts are likely to be small and positive when the water stays within the community. But when farmers want to sell water to cities, irrigation districts resist, fearing the loss of agricultural jobs and incomes that accompany rural water use. A water bank provides a clearing house to facilitate the pooling of surplus water rights for temporary rental. If well defined, its rules and procedures can reduce the costs and uncertainties associated with a transaction and increase the opportunities for both buyers and sellers.

2.8.1 Advantages of intersectoral water transfers

According to Saliba and Bush (1987) intersectoral water markets, as they function for example in the dry South West of the United States and in the semi-arid North of Chile, may offer a potential for win-win situations. Cities can buy water rights, often at a cost lower than seawater desalination or new, larger and longer pipelines. Water markets can thus reduce the necessity of subsidies for urban water. Farmers can sell part of their water rights. With the capital thus acquired, farmers have two options. They can either invest in high-value crops and water saving irrigation equipment, or they can switch to a non-agricultural activity in an urban or rural area. Saliba and Bush (1987) pointed out that this is the pattern that has resulted from intersectoral water markets in the USA and Chile. An increased participation of water users may improve the often-deficient management of irrigation systems and may increase yields, which have often remained below expectations.

Shiffler (1996) is of the opinion that reallocation of water resources seems inevitable for Southern Mediterranean countries. Faced with the challenge to supply sufficient amounts of water to rapidly growing cities, and lacking the financial means to build large seawater desalination plants, they hardly have any other option. There are two ways how to reallocate water from rural areas to the cities: through administrative decision or through the market. If water is administratively reallocated to cities, income and employment losses in rural areas remain uncompensated for and the incentives to save water in municipal and industrial use are low. A market approach to intersectoral reallocation can help to alleviate these concerns and to minimise the costs of urban-rural water transfers. Lo and Horbulyk (1996) found that water reallocation away from historical command-and-control apportionments, such as by the use of well functioning spot markets, can have a large short-term positive impact on the levels of economic welfare derived from use of this resource, especially in times of drought.

It has been shown by Vaux and Howitt (1984) that when marginal cost pricing is introduced, all water prices increase dramatically when current institutional arrangements (no water markets) for allocating water are preserved. They found that the increase in urban water prices offset the building of new capacity so long as the recipients of these supplies are compelled to pay marginal costs. When market-like mechanisms are introduced urban water users will be considerably better off by virtue of cheaper supplies and somewhat more plentiful quantities. The agricultural region will use less water, but they will do so voluntarily in response to prices offered for their water by the urban regions. With trade, no new development of water storage capacity would be justified. Trading would result in the development of excess capacity for the urban regions. This illustrates that some of the water developments in the past by urban regions have been inefficient in the sense that it would probably not have occurred had trading been permitted.

2.8.2 Concerns for agricultural to urban water transfers

Urban willingness to pay for water is typically many times higher than agricultural water productivity. Transport costs for water are high relative to the value of water *per se*. Particularly large irrigated areas close to cities are therefore likely to sell water to cities in a market setting (Shiffler, 1996). Taylor and Young (1995) pointed out that emerging water market transfers have raised concerns as to whether purchasing agricultural water for non-agricultural use benefits society. Water transfers are economically justified if new benefits, minus conveyance and transaction cost, exceed foregone benefits. Measuring benefits of foregone economic value of irrigation is key in the economic assessments of water transfers proposals.

Rosen and Sexton (1993) pointed out that substantial intra-organisational conflict can emerge within a water district in response to specific water trade proposals, and this conflict may be sufficient to defeat or delay proposed transfers that would otherwise yield substantial benefits. They suggested that the failure of public water districts to articulate well-defined property rights and to align control with those rights is detrimental to the emergence of water markets. Most analysts and policymakers agree that rural-to-urban water transfers need to be expanded. However, policy reforms are needed to facilitate these transfers. Vesting power in individuals versus organisations is needed to introduce appropriate incentives into water transfer decisions.

According to Taylor and Young (1995) the nature of stochastic water demand has thus far been emphasised because the area under those demands provides the basis for estimating the foregone benefits of agricultural water use, namely, the society's cost of agricultural-to-urban water transfers. The relatively low value of water in irrigated agriculture that made the previous generation of agricultural water storage and conveyance projects economically questionable now makes that same water vulnerable to urban transfer.

Middle Eastern and North African countries are greatly concerned about the negative indirect effects of a reduction in agricultural water use, such as unemployment in rural areas, migration to urban areas and the loss of rural livelihoods and food self-sufficiency. These concerns are not sufficiently addressed by the traditional emphasis on raising agricultural water tariffs to a cost-covering level, including capital costs. Charges for the direct abstraction from wells or rivers, in addition to tariffs for the service of transporting water address these concerns even to a lesser degree (Shiffler, 1996).

It has been shown by Hearne and Easter (1997) that although the value of water in municipal water supply is high, the value of water to profitable farmers is also high. When water is transferred from these profitable farmers for urban use the economic gains from this reallocation are small. Even if water is not used by its owner, it is generally used by other farmers. If these farmers are profitable, then the economic gains of the reallocation are small even though the financial gain to the seller is large.

Howe, Lazo and Weber (1990) pointed out that if water is transferred from agriculture to expanding uses in the same economic region, then many of the negative effects are offset locally. Most of the time, however, transfers are to uses outside the agricultural economic area. In such cases, significant uncompensated costs are imposed on the local economy. These effects are exacerbated by the use of sales proceeds to repay heavy farm debt and the absence of local investment opportunities for these funds. The results imply that states should not fear water transfers: transfers will not wreck basins of origin nor state economies. Transitional assistance, however is warranted to help those parties suffering uncompensated externalities and indirect displacement by transfers.

The State Water Project Analysis Office (1993) pointed out that some water transfers have the potential to harm the economies of areas from which water is transferred. Fallowing can have an adverse effect on local farm economies. Both United States of America State and Federal law contain a degree of protection against these impacts, and more have been proposed. Recently enacted provisions on transfers by water suppliers limit the amount of transferable water made available by fallowing to 20 percent of the water that would have been applied or stored by the supplier. Provisions in the water code prohibit transfers that would deprive areas of origin of water reasonable required to meet beneficial needs.

There are economic limits to the public purchase of water rights when social and cultural goals are sought for poor communities. Community governments are not likely to have the financial resources to buy or retain water rights commensurate with the goals being pursued. Howe *et al* (1986) used an example to explain this. Several years ago an old Spanish community in New Mexico decided to sell part of its water rights to a new ski area. The social and cultural fabric of the community was centred on the ancient irrigation system, where the channels defined property lines, supported subsistence crops and provided a common maintenance task for all the people. These values were endangered by the water sale, but the economic needs were also great. The district court responsible for supervising water transfers ruled against the transfer - the first time in the south-western United States that cultural values had been invoked in denying or modifying a water transfer (Howe *et al*, 1986).

According to the Dragun and Gleeson (1989) the ultimate threat is that if the current urban sector water reforms – particularly in the area of pricing – are applied directly to the irrigation sector, farmers will suffer a good deal of hardship and dislocation.

2.8.3 A vision for the future of intersectoral water transfers

Intersectoral water transfers have far-reaching implications for irrigated agriculture and for the economies of the different economic regions, especially for the countries faced with high population growth. Shiffler's (1996) vision of irrigated agriculture and agricultural trade in a globalised economy in one or two decades from now is as follows:

- In rural areas reached by pipelines built to supply cities, the cropping pattern is likely to change rapidly.
- Crops with a low value per unit of water (such as cereals) will be cultivated less, while crops with a high value per unit of water (such as vegetables and fruits) will be cultivated more.
- The share of crops irrigated with treated urban waste water will drastically increase.
- The change in the cropping pattern towards high-value crops will increase the agricultural interdependence of water-rich and water-poor regions. Cereals may increasingly originate from the rain-fed parts, while vegetables and fruit may increasingly be cultivated in the rain-poor parts where water has a high value.
- A phased reciprocal import liberalisation under the terms of WTO will complement such a process based on the comparative advantage of nations in agricultural

production.

- Intersectoral water allocation has the potential to release sufficient water even for rapidly growing cities.
- If intersectoral water markets are allowed to function, they will lead to the import of even larger amounts of "virtual water" in the form of cereals into the rain-poor regions.
- The notion of self-sufficiency in cereals, which most countries of the arid regions *de facto* had to abandon during the past decades, will have to be renounced by even more regions. Food security and the entitlement to food for the poor, however, can be achieved by importing cereals and generating the necessary foreign exchange by other more profitable agricultural, industrial and services exports.

Trade can alleviate environmental pressure on water resources, increase incomes, but at the price of increased interdependence and a renunciation of the goal of food self-sufficiency.

2.9 International experience with water markets

This section discusses examples of countries where water markets were introduced and the results that were achieved. The USA, Pakistan and India, Chile, Mexico, Australia, Peru and Spain are included as examples in order to provide a broad perspective. South Africa's own experience is also discussed. It must however be pointed out that although water use right transfers took place in South Africa in the past, there is no example of an active water market by definition.

2.9.1 Experiences in the USA

According to the U.S. Office of Technology Assesment (1993) most of the water trades and transfers that have occurred in the USA to date have involved the transfer of water from rural agricultural uses to municipal or industrial uses; some trades, however, have been made between agricultural regions. California established emergency Drought Water Banks in 1991,1992, and 1994 to reallocate water among willing buyers and sellers. Water purchased largely from farmers willing to idle land or pump groundwater rather than divert surface water for irrigation, was sold to cities and farms or used to protect water quality in the state's delta region and meet instream fish needs. Any adverse third-party impacts on the water-exporting communities were probably insignificant compared to the overall benefits of moving water to higher-value uses. Sales exceeded $68 million in 1991; they averaged less than $11 million in the later years when drought conditions subsided. Idaho and Texas have established permanent water banks and other states are now considering establishing them as well (Howitt 1994).

According to Yoskowitz (1997) the spot market for water in the Texas Rio Grande is very active. Analysis of this market has found that there is a significant difference in the price paid by various user groups in this homogeneous market. Over time this price differential has not converged. A critical analysis of the Texas Water Bank (TWB) found that its characteristics closely reflected a well-defined commodity market, unlike the Californian Drought Bank. However, it was found that hurdles still exist in making the TWB a broad effective market for water. Temporary water transfers are particularly useful for adapting to short-run changes attributable to such factors as climate variability. They are less effective in dealing with long-term imbalances between supply and demand resulting from changing demographic and economic factors, social preferences or climate. At some point, the historical allocation of water becomes sufficiently out of line with current conditions to warrant a permanent transfer of rights.

Saliba and Bush (1987) pointed out that the process of resolving the third-party issues associated with the transfer of a long-term shift in water use is often slow, costly and contentious. Proposed transfers face the hurdle of proving that a change will not harm others. This requirement stifles the development of markets in water rights. The Colorado-Big Thompson project, which has been able to avoid third-party issues, is the exception. The ongoing efforts of the coastal region of Southern California and the city of Las Vegas are more indicative of the obstacles to acquiring additional water. Both of these geographic areas face the challenge of meeting growing demands for water at a time when their traditional sources are declining and environmental considerations restrict the development of new ones. Los Angeles has already been forced to reduce the amount of water it takes from the Mono Lake region and, to comply with a mandate to improve environmental conditions in Owens Valley, will have to further reduce the city's supplies. In addition, the Southern California Metropolitan Water District (MWD), a large water supplier servicing more than fifteen million consumers including the residents of Los Angeles, is losing access to surplus water (that is, unused entitlements of other states) from the Colorado River.

According to Howitt (1994) Southern California's MWD, under a 1989 agreement, has invested more than $100 million in lining irrigation canals and other water conservation projects in the Imperial Irrigation District. In return, MWD received the right to use the conserved water, approximately 106 000 af (acre foot[1]) per year, for at least 35 years. Provisions were introduced to assure that neighbouring irrigation districts in the United States did not lose their water rights as a consequence. But the impact on irrigators across the border where groundwater recharge declined, was ignored because the Mexicans lack a legal claim to the water. San Diego receives about 90 percent of its water from the MWD and, as a junior claimant, is the first to be cut back in time of drought. To increase the quantity and reliability of its supplies, the San Diego Water Authority has agreed to fund additional conservation efforts in the Imperial Irrigation District in return for the conserved water. As originally proposed, 20 000 af would be transferred in 1999, with the annual quantity increasing to 200 000 af after ten years. Disputes with MWD over use of the Colorado River Aqueduct to transport the water have, however, delayed completion of the transaction. Las Vegas, which is already using most of Nevada's legal entitlement to the Colorado River, is seeking to buy more shares of the river from states with unused entitlements. Legal issues have undermined earlier proposals for interstate and interbasin sales of Colorado River water and enabled Southern California's MWD to take unused entitlements for free. Rising water values, however, are creating new interest in such sales in Nevada, which lacks rights to surplus flows, and in states wanting to benefit from their unused shares. In 1996, Arizona established a Water Banking Authority to purchase their own unused Colorado River water for storage in groundwater basins and possible sale to California and Nevada. Interstate sales, however, are tightly restricted; they are limited to 100 000 af per year and only when there is no use for the water in Arizona and there are no shortages on the Colorado River.

Finally water scarcity and the potential benefits of water marketing are not limited to the West. In the East, riparian rights are gradually being replaced by or supplemented with permits. The advantages of using markets to allocate these permits will grow, as the resource becomes increasingly scarce. Indeed, auctioning and trading permits are innovative approaches that might facilitate a more efficient allocation of water. It is unlikely however, that markets resembling the ones used to allocate most goods and services will ever become

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[1] One acre foot of water is the amount of water needed to cover one acre of land with one foot of water.

commonplace for transferring water. Finding expeditious ways to deal with the third-party effects that plague nearly all water rights transfers is critical if traditional market forces are ever to thrive. In the meantime, the enormous potential benefits of water marketing still wait to be tapped (Howitt, 1994).

The experience in the USA teaches that although there is often legal, institutional and administrative problems with the introduction of water markets, they work fairly well to reallocate water.

2.9.2 Pakistan and India

According to Thobani (1995) a 1990 survey of surface water systems in Pakistan found active trading for irrigation water in 70 percent of the water districts studied. In India, an estimated one-half of the area irrigated by tubewells belongs to farmers who buy water. In the Maghreb countries, private arrangements for trading water exist among farmers, even though it is illegal. But such transactions have been limited to spot sales of water or to the sale (lease) of water for a single year rather than to permanent sales of water rights. The difficulty in enforcing contracts in such a market has tended to confine the transactions to users in the same sector, often neighbouring farmers. The lack of secure, long-term access to water under such a system discourages investment in activities that require access to large quantities of water. Thus, such water markets realise only a small part of the potential gains from trade.

Meinzen-Dick (1997) pointed out that in Pakistan where agriculture is heavily dependent on irrigation, informal water markets are an increasingly important way of providing small farmers and tenant farmers with access to groundwater. The public canal irrigation system provides water to farmers who own land within designated areas, but it does not provide all farmers with adequate water supplies when they need it. Therefore, farmers who can afford it are installing tubewells as a sole or supplementary source of irrigation. Despite the growth in private tubewells, ownership remains limited to a relatively small percentage of farmers. Some tubewell owners also sell groundwater to other nearby farmers. The resulting localised, informal markets have become an important source of irrigation water for many farmers.

2.9.3 Chile

Hearne and Easter (1997) pointed out that Chile is one of the few countries that has encouraged the use of water markets in water resource management. They have shown that the market transfer of water use rights does produce substantial economic gains from trade. These economic gains produce rents for both buyers and sellers. But buyers, especially farmers growing profitable crops who buy water-use rights and individuals buying water-use rights for potable water supply, receive higher rents than sellers. Where trade was active transaction costs have not presented an appreciable barrier to trading. However, in the large channel systems with fixed flow dividers there have been very few transactions. Various factors contribute to the lack of trading, but the absence of trading in these large canal systems highlights the costs of modifying fixed infrastructure, especially for trade between farmers.

According to Gazmuri (1995), under Chile's 1981 water law, the State grants existing water users (farmers, industrial firms, water and power utilities) property rights to water without charge. It auctions new water rights. Subject to certain regulations, these rights can then be sold to anyone for any purpose at freely negotiated prices. They may also be used as loan collateral. Gazmuri (1995) is of the opinion that one of the most important outcomes of the privatisation of water systems in Chile has been the disappearance of the huge government deficit that was financed by poor people. All of the resources that are saved because of the efficiency of Chile's reformed water system now go to fight poverty with more professional and technical solutions. Before the companies were privatised, water projects and water delivery systems did not pay for themselves. The companies had an ineffective system of collecting tariffs. The water pipes leaked and were wasting water. Politically there was a conception that water should be free. All the governments in the past had fixed the tariffs below the cost of delivering the water. As a result the water companies were always in financial trouble, and their deficits had to be covered by taxes.

According to Gazmuri (1994) a new type of enterprise was created since 1985 when shares of water were transacted in the marketplace. The new water companies had to finance themselves. The price of water in the marketplace had to include all the costs of managing, operating and maintaining the water systems, collecting water tariffs and making capital investments. In the agricultural areas, farmers formed water associations, which have purchased the water irrigation infrastructure. Any new construction must be approved by 51 percent of the users. Because the farmers have to pay for such new construction, unprofitable, expensive ventures no longer exist. Farmers do not sign for projects unless they are sure that these projects will be economically viable.

Rosegrant and Gazmuri (1994) are of the opinion that because farmers buy or rent their water, their water efficiency has improved substantially. Chilean farmers irrigate 22 percent more land than before. The country has made a huge shift from traditional crops to export crops. Chile is now one of the world's largest producers and exporters of fruit. Chile is a country with extreme poverty, and many of the poor previously had no access to water. The most important item among the reforms is that, by law, the government must provide water subsidies to the poorest, smallest farmers and rural citizens who lack access to water. Now that everyone else is paying what water really costs, there is money available to pay for this. They have also been able to initiate health, nutrition and education programs.

The water system is now far more equitable than it was before. Far more people have potable water with a coverage rate of 97 percent in cities, compared to only 63 percent in 1970. In agriculture there is potable water coverage of 94 percent compared to only 27 percent in 1970. Although this remarkable improvement cannot be contributed solely to the availability of additional water supplies, as there were many other economic reforms as well, the privatisation of Chile's water made a major contribution.

2.9.4 Mexico

Following the economic liberalisation of Mexico in the early 1990's, in which the economy shifted from a centralised, highly regulated system to a market-based system, the lease or sale of water was legalised under the New Mexican Water Law of 1992 (Rosegrant and Gazmuri, 1994). According to Gonzalez-Villarreal and Garduno (1994) the rights and duties acquired by concession and permit holders are formulated in the title issued by the National Water Commission. In order to be able to give proof of the existence of rights acquired and to give legal security to others, the National Water Law established the Water Rights Public Register. The importance of this register is underlined by the fact that the law allows the transfer of water rights through market operations. The transmission of water rights among users is now allowed and regulated. The National Water Commission intervenes to ensure proper consideration of third-party effects and other externalities, as well as social and economic objectives. The commission is empowered to act both as referee and as conciliator, or to establish water reserves and allocate the resource through bidding of water rights.

Mexican farmers are empowered to sell their individual concessions to other users within the same Water User Association (WUA) area or irrigation district and receive the proceeds of the sale. When water sales do not change the intake or discharge, the only stipulation is that they be recorded. Water sales outside the district require a majority vote of the general assembly of the WUA and approval from the national government before they can proceed. All such proceeds go to the district and not the individual. Consequently, water values tend to differ between regions as water sales are primarily within irrigation districts (Rosegrant and Gazmuri, 1994). Future respecification of water districts to combine both irrigation districts and urban areas may create greater potential for trade between agricultural and urban areas (Easter and Hearne, 1995).

According to Chan (1989a) total agricultural use accounted for 77 percent of the total withdrawn in 1985, down from 80 percent in 1980. These developments seem to confirm the assertion that there is a growing trend of transfers from agricultural use to municipal and industrial use. Furthermore, there is some evidence that such transfers illustrate the market at work. In a number of instances, industry has approached irrigation farmers and paid them a far more attractive price than they could have received for their crops.

2.9.5 Australia

According to Pigram (1993) far-reaching reforms have taken place in the Australian water industry during the past decade. Extensive restructuring of water administration has been accompanied by increased evidence of willingness by public agencies to consider alternative institutional arrangements to the traditionally regulatory approach to water allocation and use. In irrigated agriculture, a market-based system linked to enforceable property rights to water is seen as preferable to rule-based management of water resources. However, significant social and economic considerations and political realities constrain the unfettered operation of water markets.

Australia is the driest inhabited continent in the world. Huge demands on Australian land and water have been created by the expansion of civilisation; by the spread of industry and urban development. Before 1886, property holders living beside rivers had all rights surrounding its use. According to Stoneham (1999) the Australian Irrigation Act (1886) abolished these rights, meaning that people wishing to irrigate were required to obtain a licence or permit in order to obtain river water. Since 1886, new acts have been passed, furthering policies on transferring water, and the right to ownership. According to Stoneham (1999) the Australian Water Act (1989) introduced provisions for water licences to be transferred within private enterprises. It also allowed for bulk entitlements, which may be held only by water authorities, to be transferred subject to parliamentary approval. These provisions allowed the transfer of water entitlements (TWE's), which helped water become tradable on the open market.

When new rights were issued, initial allocations have traditionally been made according to land based entitlements. The methods employed include shelf prices, tender and sale of rights. Prices for water entitlements are related to demand and the profitability of irrigation activities (Challen, Lindner & McLeod, 1996).

In Victoria, water is allocated on two levels. First, there is a bulk allocation of water to various sectors, such as public irrigators and rural towns (Eigenraam, 1999). At the second level, water is allocated within each broad agricultural sector. According to Eigenraam and Stoneham (1997) the Australian Rural Water Corporation has introduced transferable water entitlements. Allocations of water that would otherwise not be used, can be sold and put to economic use, benefiting the buyer who is able to expand production or produce a higher-value product. This also enables fair trade and minimal water wastage.

The legislation applies both to permanent and temporary transfers. Permanent transfers meet the needs of farmers wishing to undertake extensive on-farm improvements, expand activities or leave the irrigation sector. These licenses are issued for a maximum of 15 years. Temporary transfers are served by seasonal demands and only exist as a seasonal permit (Eigenraam, 1999). They are intended to ensure that landholders have access to sufficient water for seasonal commitments. Conditions apply to temporary transfers to ensure that the water storage is not over-committed and that water allocations of non-participating irrigators are not prejudiced. Limitations on transfers have been imposed to reflect the conditions of certain catchments and waterways. Transfers on unregulated waterways have the most stringent limitations. For example, on unregulated waterways, transfers must be from an upstream licence holder and the buyer will only be entitled to receive 80% of the volume transferred.

Challen *et al* (1996) pointed out that in Australia the control authority determines river segments or water bodies in a particular catchment allocation. Environmental concerns are also taken into account, ensuring that a stable ecosystem is maintained. Principles for tradable discharge rights consist of quantity, quality and permanent distribution. These rights may be traded in a market system, subject to any special conditions specified by the control authority. Authorities include regional, community and government organisations. At the start of each season, the current water situation is assessed on the basis of the volume of water held in storage in July, plus minimum storage inflows expected during the year. The assessed volume is first shared among high-security users and then the remainder is divided among normal-security users by allocating each a percentage of their water entitlement. Allocation levels for normal-security users are reviewed throughout the season. If inflows are better than the assumed minimal inflows, allocation levels are increased. Water users pay annual water charges depending upon their security of supply. High-security water users pay more to reflect the greater certainty of supply (Challen *et al*, 1996).

Eigenraam (1999) pointed out that at present only 60% of Australia's licensed water is used. Normal-security licensed holders can receive full allocations for fourteen years out of twenty. If all licenses were fully used the demand for water from existing holders could increase allocations by 100%. Although water is still abundant relative to requirements, there is a foreseeable need to economise further infrastructure investments and to encourage allocations of water to uses with the highest rates of return. In parts of the Murray-Darling Basin (MDB) and eastern seaboard, water is grossly overallocated and demand continues to increase. The MDB is now facing major environmental problems due to the overdevelopment of its water resources.

Water price is dependant on availability. Cost of water at the start of the season is higher due to the uncertainty of expected rainfall (Eigenraam, 1999). The lower the water prices the more likely it is that farmers will increase usage and that wastage will therefore be higher. If the price of water were to rise, the small-scale irrigators would reduce irrigation amounts, as it becomes cost ineffective (Malcolm, 1996). The main advantages of tradable water rights are that water licenses can be bought or sold by individual companies and government authorities; also recreational or environmental groups can enter the water trading market and purchase water licenses (Eigenraam, 1999). This enables equal opportunities for all groups within the irrigation community to have access to water licenses.

Limitations within the Australian water trading market include: publicly disclosing trading prices, excluding trading to non-land owners and traders receiving windfall profits. Unused water allocations are entering the market once the economic value for entitlements are at their most profitable level. The legislation does not allow for transfers of water allocations between irrigators and non-irrigators. This restricts the introduction of new uses and operators, thus reducing opportunities for improvement in primary industries. The legislation, although being implemented within the irrigation community, requires improvements for the allocation of trading rights of water. Some of the major concerns the current legislation faces include who has the authority to decide who is entitled to the water. The amount of water to be allocated to each irrigator is another problem that must be addressed. Water pricing must be carried out fairly. It is important to maintain appropriate water exchange rates. If appropriate exchange rates are not established, there is opportunity for powerful companies to buy water rights in order to prevent other, smaller companies from using the water, therefore restricting their irrigation activities. There should be guarantees to ensure that water allocations that have been purchased and not received are refunded. Compensation paid to these irrigators will ensure that they will continue their involvement in the water market, preventing corrupt activities surrounding the allocation of water rights. Administrative costs arising from the transfer of water licenses should be absorbed by Government funds to encourage the development of farming industries, especially to improve irrigation practices and water allocations (Department of Natural Resources and Environment, 1998).

According to Brennan and Scoccimarro (1999) the concept of a broad-ranging inter-state water market has been embraced by the Council of Australian Governments, but the transition to market-based allocation mechanisms has been slow. While political issues abound, there are also serious practical problems associated with the transition process, due to the difficulty in defining property rights to water. The inherent common property nature of river flows complicates the definition of property rights to water. Even in the case of irrigated agriculture, where the benefits from water use are purely private, the mechanisms of water delivery do not provide perfectly excludable rights, resulting in the potential for externality problems when water is transferred between users.

Another characteristic of river flows in the Australian environment that complicates the definition of water rights is the highly variable nature of flows. Irrigation and hydroelectric dam developments in Australia are not only used to change the seasonal pattern of water consumption, but also to smooth the consumption of water from year to year. Much of the debate about water allocation mechanisms has focussed on the management of these dams (e.g. Dudley and Musgrave, 1988; Musgrave, Alouze and Dudley, 1989; Pigram and Musgrave, 1990).

Randall (1981) noted that most Australian water resources have entered a mature phase of development. In this phase the water economy is characterised by sharply rising incremental costs of supplying water and there are greatly increased interdependencies among water users. There is more intense competition for water supplies, which expand slowly, and the aggregate effects of individual water use decisions include rising water tables and increasingly polluted and saline effluents. The Murray-Darling Basin typifies this situation where in parts there is now considerable conflict between agricultural, urban, recreation and environmental uses. There are also significant problems of water pollution and land degradation and there is a need for rehabilitation of ageing reservoirs, water delivery and drainage systems. The major issues when a water economy enters a mature phase are the optimal allocation of the water resource among competing users and methods for addressing the land degradation and environmental problems resulting from irrigation.

The principal tools for policy reform of the water industry involve supply management and demand management. Supply management tools include changes to allocation levels and supply reliability while demand management concepts involve price reform and water markets. The establishment of both permanent and tradable water entitlement (TWE) schemes in NSW have been a significant step towards improved efficiency of water resource use. Reform to the price system in NSW, however, has been slow, with significant levels of public subsidisation of water prices remaining. A properly functioning price system would be an effective allocator of resources and direct water to its most productive use, regulate the growth of water demand and promote flexibility of water use such that it is more readily directed to new socially desirable uses which may emerge and away from lower value uses (Pigram and Musgrave, 1990).

2.9.6 Peru

Peru's 1993 constitution treats land and water resources equally, and thus permits tradable property rights to water. A draft water law proposes that these rights can be traded, leased, or used as collateral. Property titles would be given free of charge to those who already hold water rights either implicitly by custom or explicitly through licenses and permits. Rights for presently unused water would be auctioned subject to protections that ensure that the availability of water to others is not reduced, that there is enough water to maintain a minimum ecological flow, and that people in neighbouring towns retain their accustomed access (Tobani, 1995).

2.9.7 Spain

According to Maass and Anderson (1978) the ownership of water is separate from the ownership of land in the Huerta of Alicante, as in Chile. Water is distributed by rotation at a fixed rate, approximately the same quality of water in each successive rotation, and the proportion of water available to any water right holder varies for each rotation depending on the water rights acquired on each occasion. Before each rotation a notice that announces the date on which the rotation will commence is posted; it informs water rights holders that they should within a prescribed period claim their "*albalaes*" or tickets for this rotation. Once allocated, tickets, available in twelve denominations for a constant supply of water from 1 hour to 1/30 minutes, are freely tradable in a public auction and an informal market. The community makes a genuine effort to provide farmers with information so they can buy and sell water intelligently and there are brokers who facilitate trading. A simulation model comparison of this system with those found elsewhere in Spain, where trading is not permitted, indicates that the market approach adopted in Alicante is the most efficient in terms of net increases in regional income. The differences are not great in times of only moderate water shortage, but are significant in conditions of severe water shortage.

A comparison of several different short-run operating procedures indicate that of the procedures that do not depend on full seasonal storage, markets and priorities by type of crop, are the most efficient. The latter procedure, however, is very inequitable and has been used only as a short-term response in severe droughts, while a market procedure ranks high in equity. The results show that markets are the most efficient of all the stream flow procedures considered. The conventional wisdom that the procedures "that rank high in efficiency will do poorly in distributing income equally among beneficiaries while those that do well in distributive equality will be inefficient", does not apply to a wide variety of conditions in irrigation agriculture" (Maass and Anderson, 1978).

2.9.8 Experiences with water right transfers in South Africa

Until 1992 the official policy of the DWAF was that transfers of water use authorisations was a legislative function and market trades were not considered as a policy option. Section 63(6) of the 1956 Water Act (Government Gazette, 1956) made provision for water transfers subject to ministerial approval. This policy along with the preferences for supply augmentation in times of shortages made it very difficult to obtain approval for water transfers. The authority to permit transfers in certain instances was only delegated to regional DWAF offices in 1989, pending the acceptance of an internal policy for this purpose. The formulation of this policy was concluded in 1993 (DWAF, 1993a). According to Backeberg (1994 and 1997) as a result, no water market activity occurred prior to 1994 because of:

- institutional failures stemming from the lack of private decision making powers over water management and water transfer issues;
- high transaction costs arising from common property problems of riparian water rights, and stringent legislative requirements for water transfers by the Minister;
- water rights were linked to land ownership or use through riparian rights to water; and
- preferences for judicial and bureaucratic allocation of water rights was retained by the DWAF.

The new South African National Water Act (1998) provides the framework for water markets in South Africa. 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. While the National Water Act mentions water markets as possible option in water allocation, the effected legislation however, is not clear on the provision for legal transfer of water use licences. Legislation regarding water trading is vague, creating much uncertainty about legal water trades, and the extent of bureaucratic control and regulation of water trading in the new water legislation creates highly restrictive conditions for voluntary transfers between willing buyers and sellers (Armitage, 1999). Even if water markets are introduced the above factors will increase transaction costs and will undermine the working of an effective water market. The water allocation debate in South Africa is far from over.

2.10 Overview of modelling approaches followed and results obtained

The impact of water markets, as alternative to administrative water use right allocation, has never been modelled in South Africa before. The reason for this is probably that the old Water Act (1956) did not make provision for alternative mechanisms. This study relies on modelling approaches adopted by researchers in other countries and on some of the latest modelling additions to the "Standard" spatial equilibrium approach of the type by Takayama and Judge (1964 and 1971).

The intention with this section is to provide the reader with a background of the different approaches followed by other researchers when modelling water markets. A selection of a modelling approach for this study will be discussed in Chapter 4.

2.10.1 General remarks on the modelling of water markets

Rogers *et al* (1996) pointed out that the value in alternative uses and opportunity costs are determined simultaneously when water supplies match water demands for user sub-sectors over time and space. Water markets, if functioning, will perform these functions of matching water demands (both for quantity and quality) with supplies, if appropriate policies (regulatory and economic incentives) are used to take care of externalities. In the absence of such well-functioning water markets, efficient water allocations (and resulting values and costs) can be obtained by using multi-period, multi-location systems analysis models. With the advent of high-speed computers and efficient software, it is now possible to obtain empirical estimates of values and costs using a systems analysis model on a personal computer.

Rogers *et al* (1996) are of the opinion that where such systems analysis models are not available for the practical purposes of estimating values, costs and tariffs, a partial equilibrium approach should be followed. This requires estimating the opportunity cost of water when used in a particular sub-sector in order to reflect the cost to society of depriving other sectors of the use of this water. For example, while evaluating the full economic cost of water used in the industrial sector, it becomes necessary to estimate value in the best alternative foregone, which may be urban households, mining and agriculture. Similarly, estimating the economic cost of water used in irrigation requires the estimation of the value of water used in the industrial and urban sectors.

Archibald and Renwick (1998) pointed out that a gains-from-trade model measures the potential social gains from the exchange of water-use rights. Before gains can be measured, the value of water-use rights must be known. The model is developed initially under the assumption that agricultural producers are the likely participants in developing water markets. A producer level profit maximisation model is employed to calculate the value of water in its current uses. The resulting marginal value product of water in its current use provides a measure of the short-run value of the water-use right, conditioned with relation to the type of rights and water sources. The profit maximisation model explicitly incorporates water allotment and purchase price based on water-use right and source, water market buy and sell decisions and associated transaction costs. The net gains to society from trade in water-use rights in a short-term market can be defined as the total change in the value of the water-use right, less total transaction costs for buyers and sellers. Where the change of the value of the water-use right includes the change in value for both buyers and sellers, and is measured as the marginal value product of water in its current use.

Challen, Linder and McLeod (1996) argued that many economic models of allocation mechanism have ignored transaction costs. The extent to which water would be allocated to its highest value would be constrained by transaction costs arising from (1) restrictions on the availability and processing of information; (2) problems and costs of monitoring and information collection; and (3) the need for general consensus to be achieved in allocative decisions. In a water market, trade is constrained by the transaction costs; the marginal value of water to each participant differs by the value of the transaction costs. Where the initial difference in water value between two users is less than the transaction cost, no trade will take place. It can therefore be concluded from Challen *et al* (1996) that the extent of trading in a market for water rights, and consequently the potential for a market system to improve water allocation, is dependent upon differences in supply and demand schedules between water users, and the magnitude of transaction costs.

Beare *et al* (1998) are of the opinion that the incorporation of endogenous water demand and yield response has received considerable attention in the literature in the past. However most studies focused largely on the water demand side to the exclusion of physical specifications of the water supply.

2.10.2 Approaches followed in previous studies

According to Beare *et al* (1998) a range of work has been undertaken to simulate water markets. These studies can be broadly separated into those which model water use at the farm level and those which determine demand at an irrigation region level. This distinction is reflected in the basis used for water allocation (for example, maximise farm revenue or irrigation region revenue) and hence the resulting price at which water will be traded.

2.10.2.1 Studies using farm linear programming approaches

Clark et al (1986) developed a static linear programming model (LP) for determining the short-term demand for irrigation water. The objective function of the model was to maximise the total gross margin for the region. Constraints included physical resources such as water availability, channel capacities, land types, as well as labour and crop rotational requirements. The matrix included four sub-matrices, each representing a single sub-area in terms of location and farm size. The estimation of price responsiveness of demand involved the parameterisation of the price of water over a likely range of water and product prices. A series of results was generated by the LP model, and the price-quantity relationships were summarised by means of a regression equation. It was found that the short run price elasticity of demand for irrigation water was below unity.

Moore and Hedges (1963) applied static linear programming to estimate individual farm demand functions for differing farm sizes in California, USA. The individual farm demand relationships were then aggregated by means of weights based on the distribution size in the study area. A regression equation was then fitted and the aggregate demand curve and elasticities of demand were estimated.

There have been a number of applications of parametric linear programming to estimate the demand function for water in Australia. Flinn (1969) used a similar approach to than of Moore and Hedges (1963), by estimating the regional demand for water by aggregating the demand functions determined from five individual farm linear programming models of the Yanco Irrigation Area. An important feature of Flinn's work was the estimation of intra-seasonal as well as seasonal demand functions. Flinn (1969) argued that the elasticity of demand for water would differ between the seasons of spring, summer and autumn. Flinn also pointed out that the shadow prices of institutional constraints imposed on a quadratic programming model of a river basin are generated in the same way as the opportunity cost of physical constraints. Thus it would be possible to compare the economic cost of administrative decisions with policies based on efficiency criteria alone. Within the same framework, transfer payments resulting from existing allocation policies could be measured. Similarly the financial gains and losses by the individual water users resulting from changes in existing water policy in a river basin could be predicted.

Gisser (1970) used parametric linear programming to estimate demand functions for imported water as an alternative to depleting groundwater reserves in the Pecos River Basin in the USA. Gisser was able to use these functions to calculate regional incomes from various price scenarios for imported water.

Hamilton *et al* (1989) examined the potential for using a market to shift water from irrigation to a hydropower user in periods of low river flow in the Snake River Basin of Idaho. A model of crop growth and water use was used to estimate farmer responses and resulting farm income losses caused by market restricted irrigation water supplies. Their results support the hypothesis that the marginal value of water in irrigation is relatively low.

Jones, Musgrave and Bryant (1992) analysed water allocation scenarios and irrigation supply reliability in the Murrumbidgee Valley of the Murray Darling Basin. They used a hydrology simulation model to generate annual announced allocation percentages, which were then fed into a deterministic linear programming model. This model then calculated optimal annual net returns from irrigated agriculture under various water allocation scenarios. However, the assessment of supply reliability is somewhat distorted by their assumption that water demand and supplies are assumed to be known with certainty at the beginning of each irrigation year and there is no transferability of water between users.

Further, crop yields are unresponsive to water supplies, and agricultural production in one year is assumed to be unrelated to the previous year's activities. Hence, the model does not consider the impact on water demand of either horticultural crops or annual crop rotation decisions.

Kulshreshtha and Tewari (1991) calculated derived demand functions for different farms using variable resource price programming. That is, a base farm plan was obtained using the base water prices, and the base price was estimated as the per-acre charge paid by a farmer to the water corporation plus the cost of pumping the water. Then, successive farm plans were obtained by raising the water price until water use on that particular farm became uneconomic. Thus different points representing water use along with water price on the farm level derived water demand schedule were obtained. The aggregate demand schedule for water is obtained by adding different farm-level derived demand schedules weighted by the respective area under each crop in the district.

Tisdell (1996) used linear programming models to estimate demand for water, which maximise the net revenue from irrigated production subject to cropping patterns, availability of irrigable land and the distribution of water entitlements. He concluded that the current water charge in the New South Wales-Queensland Border Rivers region is well below its long-term equilibrium price. However, his analysis indicated that the revenue generated by payment for extractive uses of water would likely be insufficient to meet the full cost of supply and, hence, a policy of full cost pricing for water in the region studied may not be viable. Tisdell further suggests that uncertainty with respect to announced allocations; future weather patterns and crop prices would inhibit the efficient allocation of water via a market and result in a price for irrigation water which is relatively unstable.

2.10.2.2 Studies using a regional or spatial equilibrium modelling approach

Vaux and Howitt (1984) developed an interregional trade model to assess the benefits of market-like exchanges of water. Their particular trade model incorporated two features not found in the conventional models of the sort suggested by Takayama and Judge (1964). The first is the introduction of curvilinear demand relationships, which improve the estimated demands for irrigation water. The conventional practice of approximating demand relationships with linear functions may introduce distortions into trade models. Leftward movements along linear demand curves (which occur with trade) inevitably entail increases in the point elasticity of demand. When justified by empirical evidence, the use of curvilinear demand functions modifies this trend towards higher elasticities and leads to more accurate estimates of price and quantity changes over the range where those changes are most likely to occur. A second departure was the inequality between the numbers of supply and demand functions. This feature permits the modelling of distinct sources of water supply that serve the same region. In effect, the common case of multiple supply regions serving a single demand can be modelled.

Hall, Poulter and Curtotti (1994) developed a spatial equilibrium model to represent the main irrigation areas and river pumpers in Australia's southern Murray Darling Basin. The regional linear programming models are linked by a series of channel constraints to represent the river system and by a model of water supply and demand. While water trading and changes in water use in each region are modelled, the model does not simulate the water use decisions of individual farmers within regions. Hence, each modelled region contains several irrigation districts and encompasses a variety of farm types. Furthermore, the model is an annual representation based on average seasonal conditions. In reality, variability between seasons within a year has implications for water and land use as well as for the timing of irrigation and the capacity of water delivery infrastructure. Climatic variability between years has implications for risk management by farmers. Without seasonal variation, the model provides no scope for assessing the implications for the value of water of irrigation supply reliability.

Lo and Horbulyk (1996) developed a spatial equilibrium model to analyse the impact of rural-urban water reallocation in Southern Alberta, Canada. Seasonal water supplies were presented by an infinitely inelastic supply curve. On the water demand side they included agricultural demands, urban and industrial demands, in-stream flow needs and water requirements to meet inter-provincial apportionment agreements. Agricultural and urban demands were represented as linear inverse demand functions for each demand region. The regional agricultural demand functions were aggregated to represent current water usage levels. Urban and industrial demand curves were derived by observing current quantities demanded and municipal water rates and applying elasticities of demand values from the western United States. However, they did not include transaction costs in the model and therefore the level of trade and potential welfare gains could have been overstated.

Eigenraam, Stoneham, Branson, Sappideen and Jones (1996) and Eigenraam and Stoneham (1998) made use of both linear programming and spatial equilibrium models to determine trade flows and water values. However, the level of trade was considerably overstated in these studies. First, as in Hall *et al*, (1994), the physical constraint of gravity was ignored in calculating the level of upstream substitution which can occur, resulting in a gross overstatement of the amount of trade physically possible. Secondly, these models assumed both allocations and irrigation requirements to be known with certainty at the start of the irrigation season. Thirdly, when determining water demand, Eigenraam *et al* (1996) did not take into account the marginal costs associated with perennial crops or annual crops which had already been planted. In applying these models to varying conditions of high and low availability, the quantities of water available for trade may again be overstated, particularly in low flow periods.

The model developed by Beare *et al* (1998) uses of the water demand relationships for Murimbidgee Irrigation Area broadacre farms derived by McLintock and Gooday (1998), but extends the analysis to allow water prices to be determined endogenously. The spatial equilibrium model also assumes that trade in water within an irrigation region can occur at a price determined by region supply and demand.

Jones and Fagan (1996) used parametric linear programming to derive product supply and input demand functions. By programming a number of representative farms or irrigation districts within an area, demand functions for irrigation water can be derived for each type of farm. The result is stepped demand functions to which ordinary least squares regression analysis can be applied. The excess supply and demand functions can then be calculated directly from the estimated demand functions for each region. These functions are then incorporated into a spatial equilibrium model for irrigation regions. Jones and Fagan (1996) used the net social revenue objective function which is a primal-dual formulation of the standard spatial equilibrium model.

Sturgess and associates argued, according to Jones *et al* (1996), that a regional model rather than models of representative farms within regions, would be able to capture the essential elements of water demand in regions. They argued that as "regional consequences are being considered, further disaggregating was not considered a worthwhile addition to model complexity and research time".

Becker (1995) explored the implications of the transformation of the system of water resources allocation to the agricultural sector in Israel from a one in which allotments are allocated to the different users without any permission to trade water rights. A spatial equilibrium model is used for the entire Israeli agricultural sector, in which an optimal allocation of the water resources is found and compared to the existing one. By using the dual prices of the primal problem a forecast is made of the equilibrium prices and their implications for the different users.

Lee and Howitt (1996) developed a non-linear spatial equilibrium model to analyse regional agricultural production and salinity control. Significant to their work is the “new” two-step procedure developed by Howitt to calibrate agricultural production models which he named “Positive Mathematical Programming”.

Wong and Eheart (1983) developed a simulation model to analyse the efficiency of marketable water right systems. They found that higher efficiency is obtained for market systems than for nonmarket policies and that the markets systems recoup about 95 percent of the economic value of the optimal distribution. The result suggested that the 5 percent efficiency loss should be attributed to the design of the market system itself, rather than the users' inability to predict future events.

Flinn and Guise (1970) developed a interregional equilibrium model of the type by Takayama and Judge (1964) as a basis to derive the optimal allocation and pricing of regulated supplies of water in a river basin. The model assumed that a river basin authority acts as the sole public utility distributor of water over time and that the capacity to supply water within any time period may be constrained by the physical structure of the system. The results of the model pointed out that the differences in equilibrium prices between regions are a consequence of the differences in transaction and delivery costs between the regions.

2.10.3 Specifications of spatial equilibrium models and the PMP methodology

It is concluded from the previous section that spatial equilibrium methodology is the most appropriate for the purpose of analysing water market behaviour. Although there are different approaches with regard to the construction of water demand functions, they all used the spatial equilibrium model (SEM) approach. Two alternative specifications for the objective function are the quasi-welfare objective function (Takayama and Judge, 1971) and the net social revenue objective function (MacAulay Batterham and Fisher, 1989). Generally a primal-dual form is used for the net social revenue SEM. For the purpose of this study the quasi-welfare SEM is referred to as the "standard" SEM and the net social revenue SEM as the "primal-dual" approach.

An important contribution to improve farm as well as regional models was the development of the Positive Mathematical Programming (PMP) technique to calibrate mathematical models. Several authors (e.g. Howitt, 1995; Arfini and Paris, 1995; Heckelei, 1997; Paris and Howitt, 1998) describe this methodology as a method for calibrating models of agricultural production and resource use using non-linear yield or cost functions. Only one example could be found in the literature where the technique was applied to water allocation models. Lee and Howitt (1996) used this method to calibrate a regional model of agricultural production and salinity control. The next section will give a short description of the "standard" and the "primal-dual" spatial equilibrium approach as well as the PMP technique for model calibration.

A detailed description of the methodologies can be found in Appendix B.

2.10.3.1 The "standard" spatial equilibrium approach

The available literature on the theory and application of the "standard" spatial equilibrium methodology is extensive (e.g. Takayama and Judge, 1964 and 1971; Flinn and Guise, 1970; MacAulay *et al*, 1989; Easter *et al*, 1997). The objective function with the "standard" spatial equilibrium approach is to maximise total welfare (consumer plus producer surplus).

According to Gardner and Fullerton (1968) maximum productive efficiency can be said to exist when the factors of production are used in optimal proportions with optimal technology and are applied to those uses where total value product is maximised. The economic welfare of the owners of production is a function of the productive efficiency of the factors and, in turn, the economic welfare of the community is a function of the welfare of the factor owners. Theoretically, provided that there are no externalities, each factor will be optimally allocated when the values of marginal product of that factor in various uses and among competing users are equal. In a perfectly competitive market in equilibrium, factor prices will be equal to the values of marginal product for all factors.

Gardner and Fullerton (1968) also pointed out that one of the conditions for perfect competition is that factors are free to seek employment where they can bring maximum returns to their owners. If factors are immobile because of transfer restrictions, it is probable that the values of marginal products will be below optimal levels in current uses and that observable market prices will reflect the lower productivity.

2.10.3.2 The primal-dual formulation for spatial equilibrium models (SEM)

Batterham and MacAulay (1994) describe an alternative to the "standard" equilibrium approach. The main deviation from the spatial equilibrium methodology (quasi-welfare objective function) as described by Takayama and Judge (1971) and this methodology lies in the use of a primal-dual formulation (net social revenue objective function) for the problem presented. The farm linear programming models are embedded in the spatial equilibrium model and replace the estimated farm or regional supply functions of the "standard" spatial equilibrium model. The primal formulation of the "primal-dual" is exactly the same as for the "standard" spatial equilibrium model formulation.

The advantage of this formulation lies in the direct link between whole farm linear programming models with the spatial equilibrium model (hereafter referred to as SEM) in terms of price as well as quantity. Both price and quantity is therefore endogenous. According to this method, both the farm model and the SEM are specified in the primal-dual form to make the linkages. The objective function value (net social revenue) at equilibrium with a primal-dual formulation is equal to zero. The reason for this is obvious in the sense that both quantity and prices are included in the objective function.

According to Batterham and MacAulay (1994) farm linear programming models are embedded in the SEM and replace the estimated farm or regional supply functions of the standard SEM. With price and quantity linked farm and SEM's, assumed changes in any part of the production and marketing system can be analysed in terms of the consequences on any other parts of that system.

According to Batterham and MacAulay (1994) three methods have been used to estimate supply functions at the farm level. They are econometric methods, producer panels and linear programming. Because of the complexity of the whole farm system the first two methods are not very accurate. Although linear programming has its disadvantages, the principal advantage is the flexibility of the behavioural assumptions. It is fairly easy to model farm behaviour by including stochastic elements and by integrating technology, biology and economics. The end result can be an acceptable representation from the real world situation. The representative farms should exhibit proportional variation in the farms modelled.

Various techniques can be applied to calculate the aggregate supply and production costs for a region (Batterham and MacAulay, 1994). Aggregation factors can be used to aggregate typical farm yield and other factors to present a regional supply and demand. The aggregation factors can be refined by simulating the present system and to compare the output per region to the statistics. While constructing the farm models it is essential to separate the production and marketing activities since the marketing activities are the link to the SEM model for the commodity in question. The marketing activity forms the transfer vector from the farm model into the regional supply row of the SEM. The objective function coefficient for the marketing activity in the farm model is zero since it is specified in the SEM part of the model. ***The objective function values for the farm models thus represent the net variable supply cost of the community to the SEM.***

According to Batterham and MacAulay (1994) both the SEM and the farm models are initially specified in terms of the primal formulation. The reason for changing the farm models to a primal-dual formulation is to replace the supply functions in the standard spatial equilibrium models. When solved on their own in this way, they will, as with the SEM primal-dual, have an objective function value of zero. The dual variables of the farm models are the shadow prices on the resource constraints given the prices determined in the SEM. In the dual part of the SEM the regional supply row becomes the regional supply price row.

This regional supply price is the price used in the dual part of the farm model. At the optimal solution the models shadow prices on the commodity balances (supply to the SEM) are equal to the corresponding commodity prices. Also at the optimum each commodity price is equal to the corresponding marginal cost of production. The marginal costs are defined as including both the explicit costs of purchased inputs and the opportunity cost of fixed resources at the margin. In the primal-dual formulation the supply price to the SEM therefore includes, as in a competitive market, the cash costs as well as the opportunity cost of production. Thus, the farm model is linked to the SEM in two ways, by quantity through the primal part of the farm and SEM, and by price through the dual part of these models.

According to MacAulay *et al* (1989) it is worth noting that the net social revenue formulation for spatial equilibrium models is essentially a primal-dual formulation. For this reason the objective function is zero since the value of the objective function of the dual formulation is subtracted from the value of the primal objective function.

A major disadvantage of this approach is the practical problem of specifying a complex model both in terms of the primal and the dual formulation. MacAulay *et al* (1989) developed a Fortran program to convert the primal formulation into a dual formulation to overcome this problem.

2.10.3.3 The Positive Mathematical Programming (PMP) approach

Arfini and Paris (1995) pointed out that one of the main goals of economic analysis is to determine how market equilibrium conditions can possibly be reached while changing some of the parameters affecting the operators' decision-making process. In theory this is done by a "comparative statistics" analysis, whereas in practice, as long as adequate information is available, econometrics is used. In the latter case, the appropriate methodological approach requires that the economic analysis issue be dealt with in two separate phases: estimating and forecasting. The former entails the econometric model calibration, including verification tests. Forecasting, on the contrary, is designed to analyse the model behaviour in other conditions than the initial ones, thus providing a measure of the changes resulting from the newly introduced parameters.

According to Howitt (1995) programming models should calibrate against a base year or an average over several years. Policy analysis based on normative models that show a wide divergence between base period model outcomes and actual production patterns is generally unacceptable. However, models that are tightly constrained can only produce that subset of normative results that the calibration constraints dictate. The policy conclusions are therefore bounded by a set of constraints that are expedient for the base year, but often inappropriate under policy changes. This problem is exacerbated when the model is on a regional basis with very few empirical constraints, but with a wide diversity of crop production. It is comparatively rare that agronomic practices are fixed at the margin; more commonly they reflect net revenue maximising trade-offs between yields, cost of production, and externalities between crops. In the latter case, rotations are functions of relative resource scarcity, output prices and input costs.

Howitt (1995) described PMP as a method to calibrate models of agricultural production and resource use by developing non-linear yield or cost functions. The non-linear parameters are shown to be implicit in the observed land allocation decisions at a regional or farm level. The PMP approach uses the farmers' crop allocation in the base year to generate self-calibrating models of agricultural production and resource use, consistent with micro-economic theory, that accommodate heterogeneous quality of land and livestock. While the PMP approach is unconventional in that it employs both programming constraints and "positive" interferences form the base-year crop allocations, it has one strong attraction for applied analysis: **it works** (Howitt, 1995). The PMP approach automatically calibrates models using minimal data, and without using "flexibility" constraints. The resulting model is more flexible in its response to policy changes, and priors on yield variation or supply elasticities can be specified.

Howitt (1995) stated that the PMP approach aims to achieve exact calibration in hectares, production and price. The approach is developed for the majority of modellers who for lack of an empirical justification, data availability or cost, find that the empirical constraint set does not reproduce the base-year results. The LP solution is usually an extreme point of the binding constraints. In contrast the PMP approach views the optimal farm production as a boundary point, which is a combination of binding constraints and first-order conditions.

Paris and Howitt (1998) pointed out that when the basis matrix has a rank less than the number of observed base-year activities, the resulting optimal solution will suffer from overspecialisation of production activities compared to the base year. A source of these problems is that LP was originally used as a normative farm planning method assuming full knowledge of the production technology. For aggregate policy models, this normative approach produces a production and cost technology that is too simplified due to inadequate knowledge. This common situation means that the analyst is attempting to estimate marginal behavioural reaction to policy changes based on average data observations.

On a regional level, information on the output levels produced and land allocations by farmers is usually more accurate than the estimates of crop marginal production costs. Accordingly the PMP approach uses the observed acreage allocations and outputs to infer marginal cost conditions for each observed regional crop allocation. This inference is based on those parameters that are accurately observed, and the usual profit maximizing and concavity assumptions. If the model does not calibrate to observed production activities with the full set of general linear constraints that are empirically justified by the model, a necessary condition for profit maximisation is that the objective function is non-linear in at least some of the activities.

Arfini and Paris (1995) pointed out the two phases of calibration as: (1) linear programming that allows estimation of shadow prices, these being dependent on the factors required to evaluate the cost function and (2) quadratic programming that can reproduce information about the base period.

According to Heckelei (1997) the PMP methodology has two clear advantages with regard to simulation behaviour:

- the response is not restricted by weakly justified constraints and
- the response is smooth compared to a standard linear programming problem.

Both points show the potential of the PMP approach to yield more realistic response behaviour of the model compared to previously employed calibration techniques.

Chapter 3

DESCRIPTION OF THE STUDY AREA

3.1 Introduction

The purpose of this chapter is to give the reader an in depth overview of the Upper-Berg River in terms of its water balance, agricultural production areas, irrigation practices and typical farms in the area. The following section will provide a description of the topography, climate and general land use of the area. This will be followed by a complete description of the water balance, i.e. the supply and demand for water in the area. A discussion of the quality of the water in the Berg River is provided in Section 4.

Section 5 describes the survey sampling method and Section 6 provides a discussion of the survey results. A description of the typical farms and their construction follows. The last two sections deal with the compilation of crop enterprise budgets for the area and provide a summary of the dimensions of the problems in the Upper-Berg River respectively.

3.2 The Berg River and its tributaries

The Berg River has its source in the high-lying mountainous area of the Groot Drakenstein mountains. From here it flows in a northerly direction and joins the Franschhoek Valley. The flow continues towards Paarl, before which it is joined by two tributaries. The first, situated to the east, is the Wemmershoek River, which is impounded by the Wemmershoek Dam, and the other is the Banhoek River. The Banhoek River has its source in the Groot Drakenstein and Jonkershoek mountains. It joins the Berg River from the west approximately halfway between Franschhoek and Paarl. The Berg River flows through Paarl and Wellington, where it is joined by the Krom River from the east.

This tributary has its source in the Limietbergs, and drains the valley above Wellington. Flowing northwards, the Berg River is joined by various other tributaries. The larger ones are the Kompanjies River, the Klein Berg River and Twenty Four Rivers. Also situated to the east is the Voëlvlei Dam. See Figure 3.1 for a visual representation of the Berg River, its tributaries and dams.

The Klein Berg River has its source in the high lying Winterhoek mountains in the northeast of the Tulbagh Valley. Further south it is joined by the Boontjies River. From here, it flows westwards, between the Obiekwa and Voëlvlei mountains into the Berg River Valley, and joins the Berg River to the west of Saron. Approximately 3 km north is the confluence of the Twenty Four Rivers and the Berg River. This river drains the high-lying mountainous area of the Groot Winterhoek. After a further 10 to 15 km, the Berg River flows over the Misverstand Weir. Upstream of the Weir, it is joined by tributaries that drain the areas north of Porterville and Morreesburg. From here onwards, the river flows in a northwesterly direction and drains into the Atlantic Ocean at Velddrift (DWAF, 1993e).

As has been indicated in Chapter 1 the Berg River basin was chosen as a case study because of its complex nature, the fact that it supplies, amongst others, water to the Cape Metropolis and also because of its strategic importance for highly valued summer crops in the winter rainfall region of the Western Cape. As pointed out in Section 1.5 this research is only concerned with the Upper-Berg River, which is the area from the source of the river to a farm called Sonquasdrift, situated near to the Voëlvlei Dam. The Voëlvlei Dam supplies the Lower Berg River irrigation area with water.

3.3 Natural features of the Berg River

The natural features of the Berg River are discussed in terms of the topography, climate and land-use in this section.

3.3.1 Topography

The upper region of the Berg River Basin is surrounded by high mountain ranges (RL 1500 m) to the south, east and west. The river basin is fairly narrow (10-15 km) between the sources (Groot Drakenstein) and Wellington. Northwards of Wellington, the Limietberg continues to bound the valley to the west. In the east, the basin levels out and the river valley widens to approximately 25 km (DWAF, 1993e).

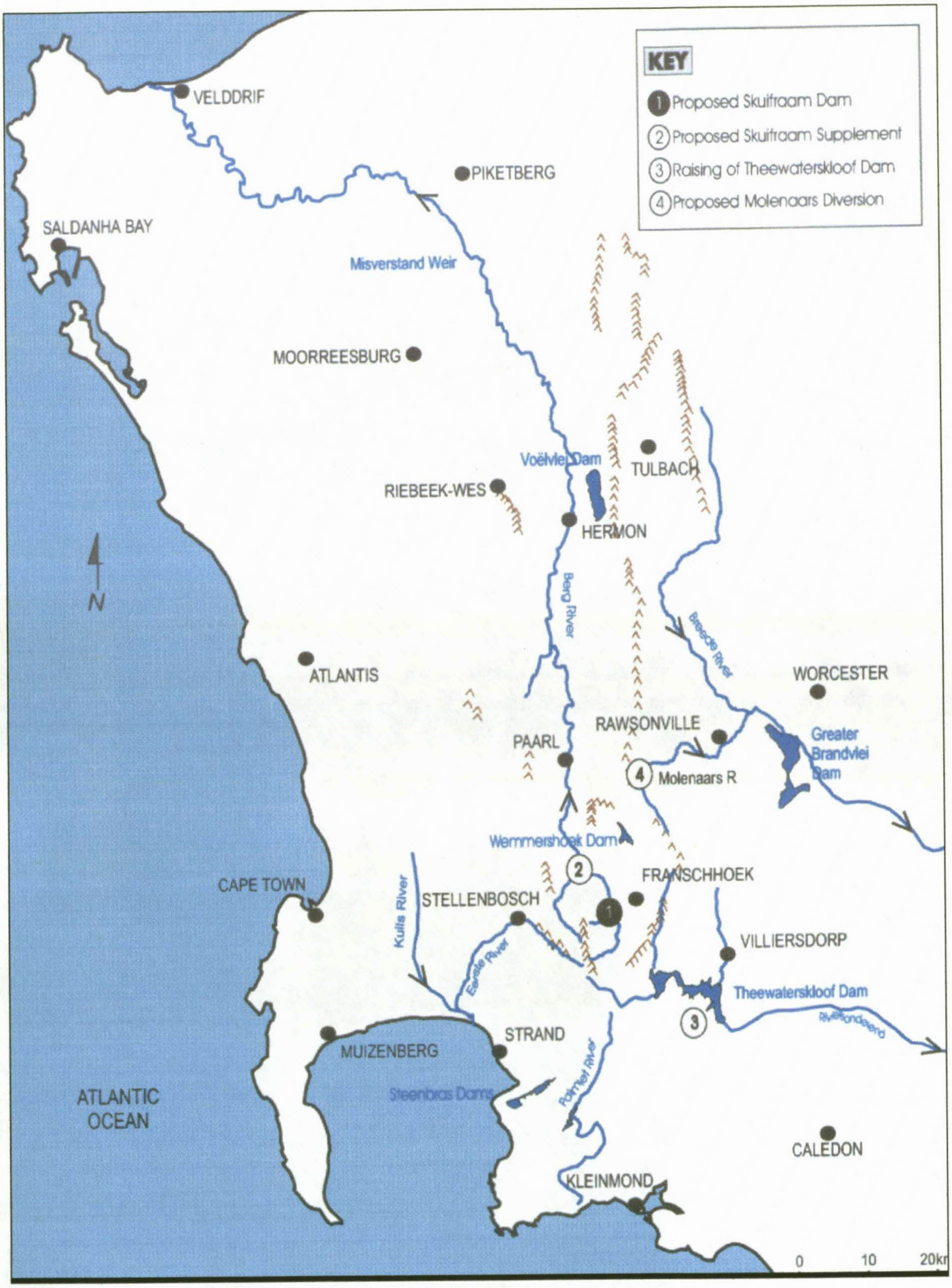

Figure 3.1 : Visual description of study area

Source: DWAF (1997a)

3.3.2 Climate

The climate which prevails in the Berg River Basin is typical of the Western Cape Region. This region is classified as a humid zone and experiences winter rainfall together with high summer evaporation. Precipitation is from cold fronts approaching the area from the north-west. As a result of the topographical influence of the mountains, a large spatial variability is experienced in the mean annual precipitation (MAP). In the high lying areas of the Groot Drakenstein, the MAP is around 2 600 mm, while further northwards, where the Berg River Basin levels out, the MAP drops to below 500 mm (DWAF, 1993e).

The area is characterised by a significant seasonal variation in monthly evaporations, which is typically 40 to 50 mm in winter, and 230 to 250 mm in the summer months. The mean annual evaporation throughout the basin show less spatial variability than the mean annual precipitation. The high rainfall/low evaporation during winter and low rainfall/high evaporation during summer is an important climatic feature of the Western Cape Region (DWAF, 1993e).

3.3.3 Land use

Land in the Upper Berg River area is primarily used for wine farming and to a lesser extent, for fruit farming. A portion of the land is irrigated with water either collected in farm dams or abstracted directly from the river and its tributaries. Lucerne, vegetables and other crops are also grown, but only in small amounts. Forestry is found throughout the Berg River Basin, but predominates in the high altitude and rainfall areas.

In the Lower Berg River areas, towards the north, land utilisation changes from wine farming to dryland grain farming, Apart from crops and forestry, indigenous "fynbos" vegetation is found in most areas. This growth varies from dense concentrations in gulleys to sparse coverings on rocky mountain slopes (DWAF, 1993e). Land use for different crops in the Upper-Berg River Basin in 1992 and 1999 are presented in Figure 3.2 and Figure 3.3 respectively.

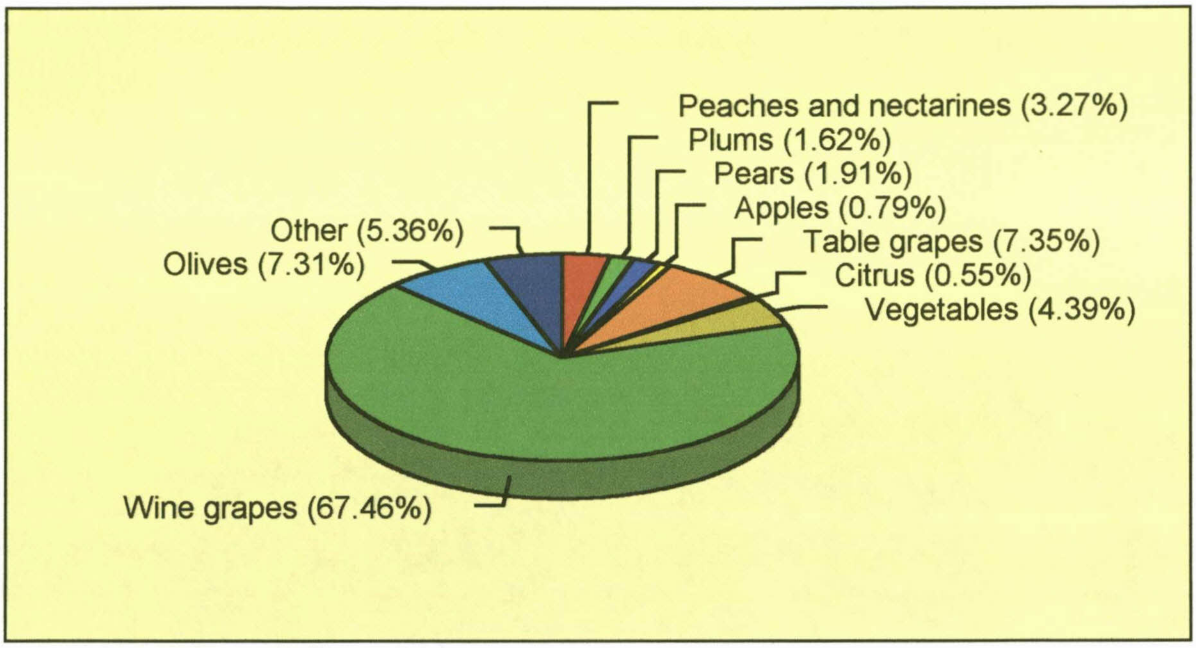

Figure 3.2: Irrigation land use in the Upper Berg River (1992)

Source: DWAF (1992b)

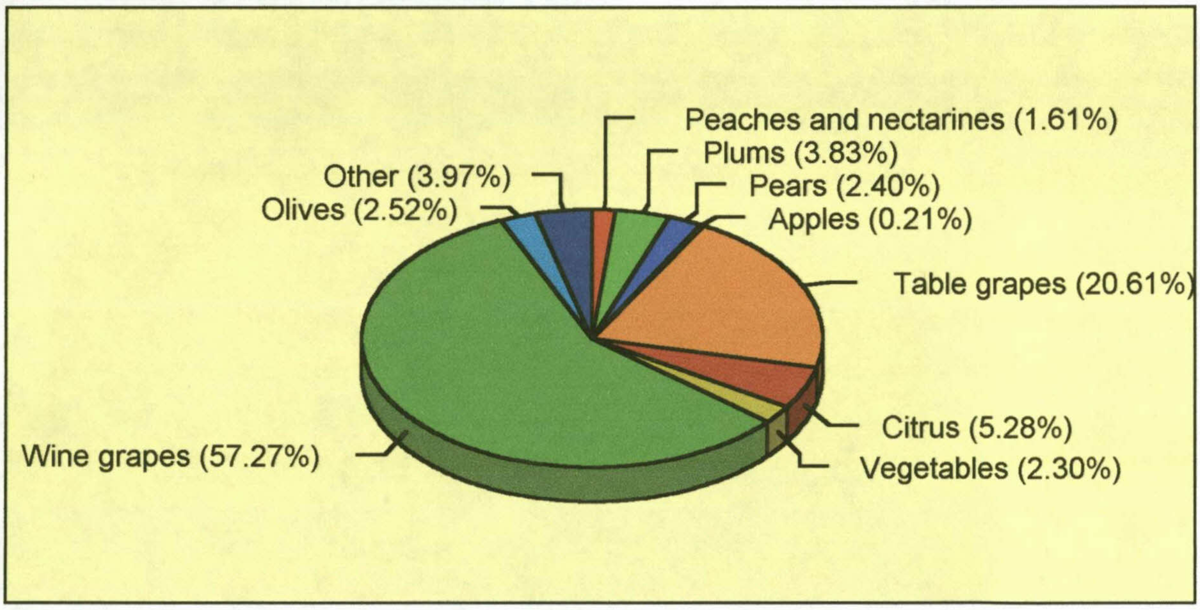

Figure 3.3: Irrigation land use in the Upper Berg River (1999)

Source: Own calculations from farm survey data

It is clear from the above figures that a significant change in agricultural land use has occurred since 1992 i.e. away from wine grapes towards fruit production. This change was induced by favourable conditions on export markets during the early 1990s.

3.4 Water supply and demand characteristics of the Upper-Berg River

In order to construct a water balance for the Upper-Berg River the water supply sources and water demand for the urban and agricultural water use sectors are discussed. The water supply to the urban sector is treated separately from the supply of water for irrigation purposes. All the water supply sources to the urban sector are discussed. The Berg River, the Theewaterskloof Dam and farm dams are the major sources of water for the irrigation sector and are also discussed here. The Theewaterskloof Dam is the only source in this study which faces potential competition between urban and agricultural water users. A short discussion of the Theewaterskloof Dam follows.

3.4.1 The Theewaterskloof Dam

According to the DWAF (1992a) the Theewaterskloof Dam (see Figure 3.1) has a capacity of 480.4 million m^3 and regulates the water flow in the Riviersonderend River. This source is supplemented by water abstraction at diversion weirs on the Wolwekloof and Banhoek streams, which are tributaries of the Berg River, and at Kleinplaas Dam on the Eerste River. Kleinplaas, which has a capacity of 0.376 million m^3 per annum, also serves as a balancing reservoir for the tunnel system. Two diversion weirs feed flows into the tunnel for distribution, as required, to the tunnel outlets at Robertsvlei near Franschhoek or to the Theewaterskloof Dam. The firm yield of the system has been calculated from historical flow sequences covering 60 years to be 207 million m^3 per annum.

The CMC (Cape Metropolitan Council) is entitled to a supply of 83 million m^3 per annum from the scheme, and in addition it uses the 7 million m^3 per annum allocation of Paarl Municipality ceded in return for the 7 million m^3 per annum that the CMC supplies from Wemmershoek Dam. Stellenbosch Municipality has an allocation of 3 million m^3 per annum, bringing the total allocation for urban use to 93 million m^3 per annum (DWAF, 1992a). The remaining water is allocated for agricultural use but because the agricultural demand has grown less than anticipated when the scheme was planned, the CMC has received a temporary additional allocation of 93 million m^3 per annum. The total urban allocation from the Theewaterskloof Dam is therefore 186 million m^3 per annum.

However, these allocations are theoretical as the real amount of water that the CMC as well as the agricultural sector receives is highly dependent on the amount of water in the storage dams at the beginning of the season. For instance during the 1999/2000 season the CMC only received 145 million m^3 of water and in the 2000/2001 season (due to low levels in the storage dams) only 123 million m^3 of water has been allocated to the CMC (DWAF, 2000). With the provisions of the National Water Act, 1998, these allocations may change again as the unused water rights presently allocated for agriculture may be reallocated.

3.4.2 Urban water supply

The Water Service Authority (WSA) referred to in this study is the Cape Metropolitan Council (CMC). The Water and Waste Directorate within the CMC is responsible for the provision of bulk water services. The CMC utilises water from various dams within the Cape Metropolitan Area (CMA) and also from dams outside the Cape Metropolitan Area (CMA). Table 3.1 shows the water supply sources for the CMC (CMC, 2000).

Some of the dams are operated and controlled by the CMC, whilst the other dams are operated and controlled by the Department of Water Affairs and Forestry. The CMC obtains approximately 70 to 75 percent of its raw water requirements from DWAF and the remainder from its own sources. Approximately 15 percent of the raw water requirements are obtained from sources within the CMA.

The yield of these supply sources is theoretical. For example the water budget for 2000/2001 indicates that only about 330 million m^3 will be available. This is the reason for the water restrictions that were imposed during November 2000 (DWAF, 2000). The growth in urban demand is so rapid, that it is believed that demand management will not stem growth in demand sufficiently and that it would be necessary to provide additional supplementary water sources.

Table 3.1 Water supply sources to the CMC

Dams/rivers	Own and operated by	Approximate % of total supply requirements	Allocation/yield Million m^3
Theewaterskloof Dam	DWAF	47.7 %	186
Voëlvlei Dam	DWAF	16.9 %	66
Palmiet River	DWAF	5.8 %	22.5
Wemmershoek Dam	CMC	14.4 %	56
Steenbras Upper and Lower Dam	CMC	9.7 %	38
Simon's Town Lewis Gay Dam and Kleinplaas	CMC	0.5 %	1.85
Land en Zeezicht Dam (From Lourens River)	CMC	0.1 %	0.5
Table Mountain: Woodhead Hely-Hutchinson De Villiers Dam Victoria Dam Alexandra Dam	CMC	1.3 %	5
Other sources			
Atlantis Boreholes	Western Cape RSC	1.1 %	4.4
Nantes Dam	Paarl	0.1 %	0.5
Berg Pumpstation	Paarl	0.6 %	2.5
Land en Zeezicht	Somerset West	0.1 %	0.5
Jonkershoek stream	Stellenbosch	1.4 %	5.5
Antoniesvlei	Wellington	0.1 %	0.5
TOTAL		**100 %**	**389.8**

Source: DWAF (1992a and 2000)

The DWAF (1997a) recommended six sources for further investigation. These are shown in Table 3.2 (also see Figure 3.1 for the location of Skuifraam and Molenaars schemes).

Table 3.2: Possible sequence of schemes suggested by the Western Cape System Analysis (WCSA)

Scheme	Scheme Yield $m^3 \times 10^6$	Commissioning Year	Relative cost of water
Palmiet 1*	31	1998	1
Voëlvlei/Lorelei 1	15	2000	1.3
Skuifraam Dam	72	2001	2.4
Molenaars Diversion to Skuifraam	37	2005	1.9
Lourens River Diversion	20	2006	1.8
Cape Flats Aquifer	18	2008	2.2

Source: DWAF (1992a)

* Already in operation. Base for index of relative cost comparison.

The Skuifraam Dam is most likely to be the next major dam to be constructed in the Western Cape. The envisaged cost of the Skuifraam Scheme was estimated at R780 million or R0.57/m^3 in March 1999 and it is envisaged that the CMC would be responsible for repaying a large portion of this capital investment (DWAF, 1992a). The building of this dam is highly controversial. To highlight the controversy an abstract of a media release by the World Commission on Dams on the 16th of November 2000 is provided below:

"The report of The World Commission on Dams (WCD) released on 16 November has highlighted the inadequate homework done in many cases by the dam building industry prior to the construction of dams. The World Commission on Dams was chaired by Prof. Kader Asmal, former Water Affairs minister and currently education minister and comprised 12 members from various diverse fields. The commission recommends that large dam projects should only be approved if they meet the framework and guidelines as set out in the report. The call has now gone out to the World Bank and export agencies to stop supporting dam projects unless they comply with these criteria.

On the same day, Minister Ronnie Kasrils met with a wide spectrum of stakeholders in the Western Cape to discuss, amongst other issues, the construction of Skuifraam Dam. Although the decision to build Skuifraam Dam was previously put on hold by Prof. Asmal, on the basis that the CMC had no effective Water Conservation and Demand Management (WC&DM) program in place, it was recently approved by the Department of Environmental Affairs and Tourism (DEAT). In the covering letter from Minister Valli Moosa to Minister Kasrils confirming that the appeals were rejected, Minister Moosa said: 'It appears that water demand management has not really seriously been implemented in the Cape Metropolitan area.' The Minister is to be commended for further stating: 'I fully support the principle of water demand management and recommend that this approach be given the necessary priority attention by all relevant authorities.'

While the era of supply-side tunnel vision is supposedly over, it is clear that this has not been translated into action in the Western Cape. The WCD emphasises the importance of alternatives and it is clear in the case of the Skuifraam Dam, that the alternatives which are more sustainable and more economically viable if true economic accounting took place, have not been explored or exploited in full. The government, which has so clearly endorsed the WCD process, must revisit Skuifraam Dam in light of the recommendations of the WCD. The responsibility of the government is to illustrate both the importance of the WCD process as well as its commitment to sustainable development, through retracting the Skuifraam Dam decision and the implementation of an exhaustive, independent, objective and thorough economic assessment of all alternatives and their implications."

Source: World Commission on Dams (2000)

3.4.3 Urban water demand

It is estimated that approximately 4 million people live within the Western Province and approximately 2,56 million within the CMA. The population growth rate is approximately 2,5 percent per annum. In 1996, the total population of South Africa was over 40 million. The interim population estimate of the CMA for 1998 based on the 1996 Census data is approximately 2,9 million. The age distribution reveals a young population with 26 percent (or ± 750 000 people) under the age of 15 (CMC, 2000).

The CMA has a structurally diverse economy, with key sectors being manufacturing, tourism, services and trade. The key growth sectors include financial services, construction, service and industrial niches such as food processing and high technology. Major factors affecting the economic development in the CMA have been the growth in the tourism industry and strong foreign investment interest. The CMA is the primary economic center of the Western Cape Province, with a 75 percent share in the provincial gross domestic product (GDP) and more than a 10 percent share in the national gross domestic product. The GDP of the CMA is approximately R60 billion. A list of the customers to which the CMC supplies bulk water and the share of total amount of water they consumed during the 1998/99 financial year is shown in Table 3.3.

Table 3.3: Water demand of urban users supplied by the CMC

Water service authority	**Estimated consumption (mℓ) July '98 to June '99**	**% of total consumption July '98 to June '99**
City of Cape Town	88 681	28.9%
City of Tygerberg	76 461	24.9%
South Peninsula Municipality	55 782	18.2%
Blaauwberg Municipality	26 857	8.8%
Oostenberg Municipality	24 477	8.0%
Helderberg Municipality	14 506	4.7%
Paarl Municipality	15 308	5.0%
Wellington Municipality	3 095	1.0%
Winelands District Council	1 636	0.5%
Total	**306 803**	**100%**

Source: CMC (2000)

The Water Department's 12 month moving average for unaccounted water is given in Table 3.4.

Table 3.4 : Unaccounted water 1999/2000

Monthly unaccounted for water as a percentage (%) of total water demand											
JUN 99	**JUL 99**	**AUG 99**	**SEP 99**	**OCT 99**	**NOV 99**	**DEC 99**	**JAN 00**	**FEB 00**	**MAR 00**	**APR 00**	**MAY 00**
15.52	15.47	16.38	16.59	15.67	15.03	14.47	13.35	12.95	12.6	12.09	11.98

Source: CMC (2000)

The improvement in the unaccounted-for water figures for June 1999 through to May 2000, can be attributed to improved metering and monitoring including meter repairs and replacement. The unaccounted water is also a matter of great concern. In a media release of the WDC on the 16th of November 2000, the following was said:

> *"Another neglected area is the recycling of effluent, which in the CMC, could become a major contributor to the supply equation as currently only some 8% is recycled and the rest goes to waste. According to the CMC reports at present at least 15% of water is unaccounted for although national norms indicate far higher levels of around 30 to 40%, so this statistic needs verification. Again, this represents a potential source not only of missing revenue, but also water itself."*

Source: World Commission on Dams (2000)

The Water Department monitors water consumption of the average peak week consumption in summer and compares actual consumption with that which was predicted. This is done to determine when new schemes have to be implemented to meet the annual water demand as well as when a new water treatment plant has to be constructed to meet peak demands. The planning for the implementation of new schemes is carried out in conjunction with the Department of Water Affairs and Forestry and Ninham Shand Consulting Engineers, using the Western Cape System Analysis Planning Model (CMC, 2000).

The historic growth in water demand has averaged between 3 and 4 percent per annum over the last 30 years. Whereas previously bulk water schemes were constructed to meet the growth in annual water demand, the emphasis has now shifted to limit the growth in water demand by implementing Water Demand Management (WDM) measures. WDM is essential as there are a limited number of feasible water supply schemes available and the cost to implement new schemes gets increasingly higher, both financially and environmentally (CMC, 2000).

The CMC has already announced its intention to reduce predicted water demand by the year 2010 by 10 percent. The predicted water demand figures are based on a study carried out in 1991 by the Institute for Futures Research, and the CMC has been using the Second World Growth Scenario as its projected demand growth scenario. The water demand per sector during 1998/1999 is shown in Figure 3.4 (CMC, 2000).

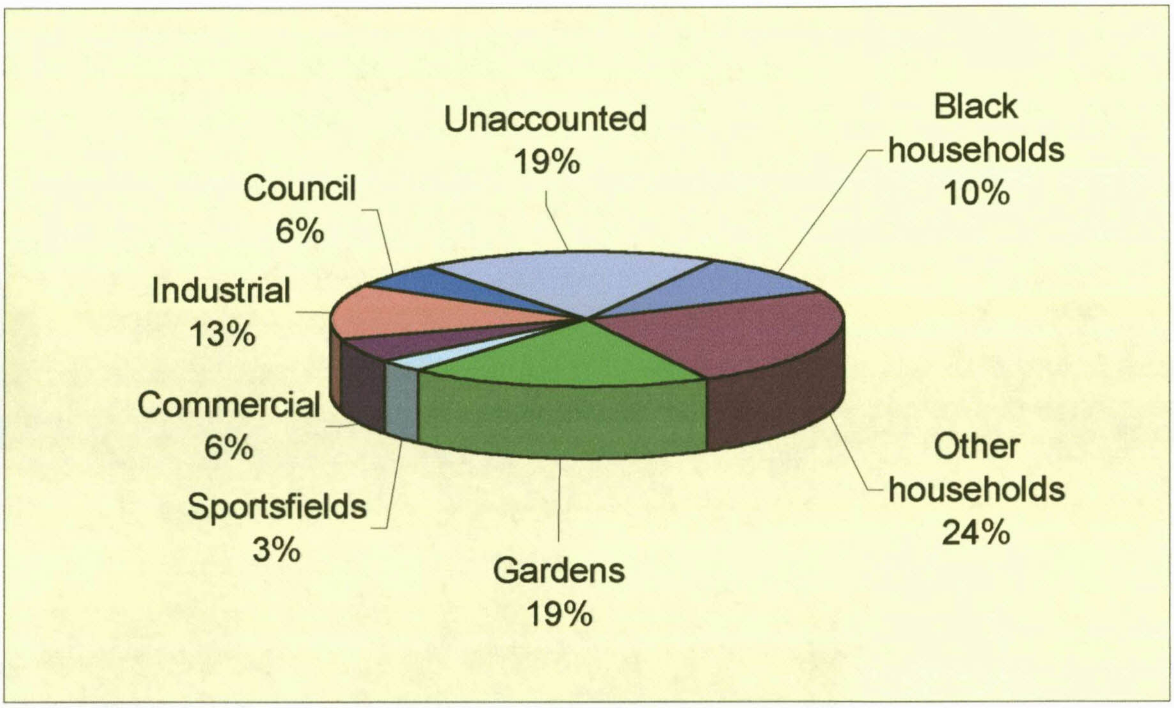

Figure 3.4: Use per urban demand sector for the CMC

Source: CMC (2000)

The expected growth in demand at an average growth rate of 3 percent (water demand management strategies not included) per annum is shown in Figure 3.5. It is clear that the water demand will outstrip water supplies in 2005 (if there are droughts in between, even sooner). This highlights the water shortages that will face the CMC and the irrigators along the Berg River in the not so distant future. Even if the Skuifraam Dam can be completed within the next four years, the demand will already have reached such levels that the new capacity will only last for another four to five years before it is also outstripped by demand. If water demand management strategies can be implemented successfully this picture will not be so bleak (CMC, 2000).

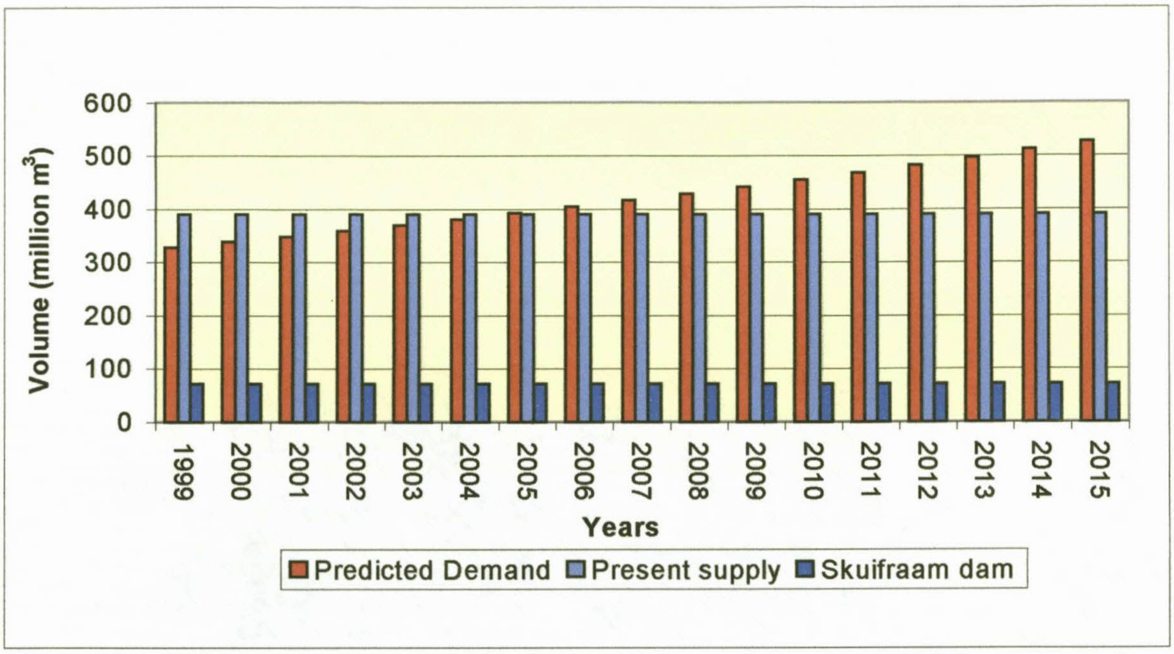

Figure 3.5: Expected growth in the urban demand for water in the CMC 1999-2015

Source: CMC (2000)

The problem is aggravated by the fact that the urban demand is also highly seasonal and that the peak demand coincides with the peak agricultural demand and the driest time of the year. This is shown in Figure 3.6. The water demand of the urban sector nearly doubles from the months of June, July and August reaching a peak during December and January.

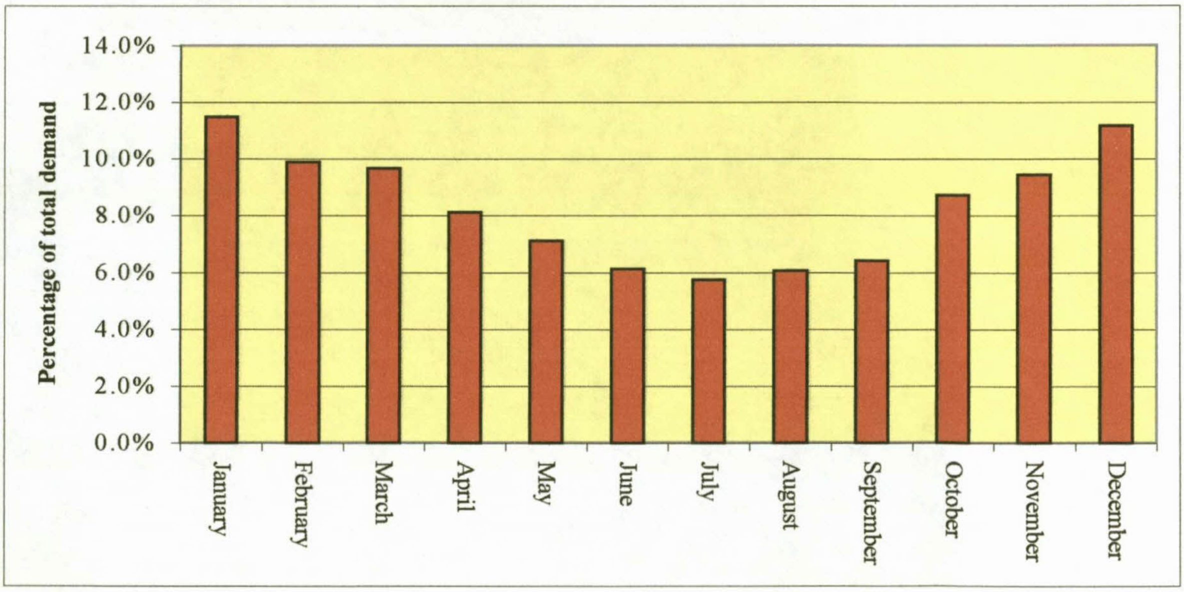

Figure 3.6: Seasonal demand for urban water

Source: CMC(2000)

This period also coincides with the peak summer tourist period when tourists from the northern parts of the country and from overseas come to Cape Town in thier thousands.

3.4.4 Agricultural water supply

According to Government Gazette (1983) the maximum quantities of water, if available, may be provided annually in respect of each hectare of land for the following areas:

- Four thousand (4 000) m^3 of water for the properties from the Franschhoek Forest Reserve up to and including the farms Sandkliphoogte 835 on the left bank and Fraaigelegen 841 on the right bank of the Berg River. Referred to as **Berg1** in this study.
- Five thousand (5 000) m^3 of water for the properties from Erf 8442, Paarl, on the left bank and Hartebeestekraal 844 on the right bank up to and including the farm Zeekoeigat 80 on the left bank and Olyvenboom 83 on the right bank of the Berg River. Referred to as **Berg2** in this study.
- Six thousand (6 000) m^3 of water for the properties from Hazekraal 58 on the left bank and Olyvenboom 56 on the right bank up to and including Portion 2 of Sonquas Doorndrift 648 on the left bank and the Remainder of Sandleegte 201 on the right bank of the Berg River. Referred to as **Berg3** in this study.

The supply of water for irrigation purposes consists of allocation water from the Theewaterskloof Dam, natural runoff in the winter (April-September) and farm dams. Although the total allocation from the Theewaterskloof Dam to the Upper-Berg River is 75 million m^3 (14 985 ha) of water, the average use has varied between 30 million m^3 and 40 million m^3 since 1997. According to the latest figures released by the DWAF the water budget allocated for the Upper-Berg River is 42 million m^3. The remainder of the agricultural water allocation, 33 million m^3, is already used by the CMC in order to meet their demands (DWAF, 2000).

During the winter months riparian users are permitted to pump an unspecified amount of water from the river. The normal practice is to fill up farm dams during the winter for use during the dry summer months. In a normal year it is not necessary to irrigate crops in the winter months. Some of the other water users have so-called winter water rights. These users may pump a specified volumetric amount of water per ha during the winter and are mostly situated on irrigation board pumping schemes away from the river. At present these allocations consist of:

- Riebeek-Wes: 75 ha with an allocation of 6 000 m^3 per ha
- Riebeek-Kasteel: 220 ha with an allocation of 6 000 m^3 per ha

The Perdeberg, Noord-Agter Paarl and Suid-Agter Paarl irrigation regions do not have any winter water rights.

The farm dam capacity varies for different parts of the river and tends to be more important in the lower parts of the Upper-Berg river (see Figure 3.7). It is clear from Figure 3.7 that the irrigators on the irrigation board schemes, Suid-Agter Paarl (SAP), Noord-Agter Paarl (NAP), Perdeberg (PB) and Riebeek-Kasteel (RK), are more dependent on farm dams than the riparian irrigators (Berg 1, Berg 2 and Berg 3). It is virtually impossible to make an accurate assessment of the total farm dam capacity of the Upper-Berg River. However, it has been estimated by the DWAF (1993c) that during 1990 conditions the total capacity of farm dams was 37.858 million m^3. It has been shown by the DWAF (1993c) that from 1980 the farm dam capacities increased less rapidly, indicating that the basin is reaching full development. In order to calculate a water balance it was assumed that the total farm dam capacity for the Upper-Berg River is 40 million m^3.

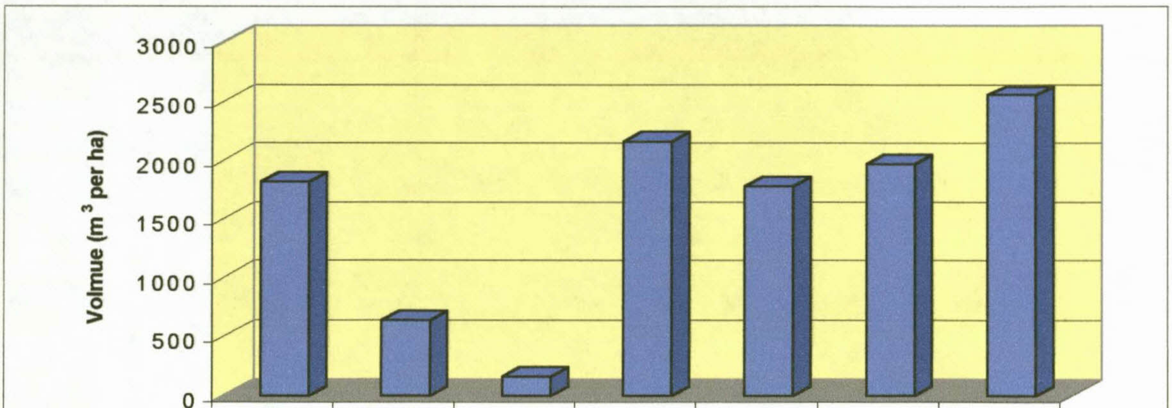

Figure 3.7: Regional farm dam capacity

3.4.5 Agricultural water demand

According to the DWAF (1992b) the demand for the irrigation sector was forecasted to increase from 30 million m^3 in 1995 to 70 million m^3 per annum in 2010. However, it should be noted that there has been a moratorium on further allocation of irrigation water since 1995. This moratorium slowed the rate of water demand growth, although trading of unused water rights continued. DWAF (1992b) assumed that the need for irrigation water will be determined by:

- the market potential for products (mainly deciduous fruit, vegetables, wine grapes and citrus);
- the availability of land for production; and
- the relative production-economic competitiveness of the area.

Figure 3.8 shows the actual annual withdrawals by the Berg River Irrigation Board from the Theewaterskloof Dam for the 1993/94 to 1999/2000 water years. Although withdrawal varies between water years it is clear that the forecasts of 1995 were, to a great extent, overestimates.

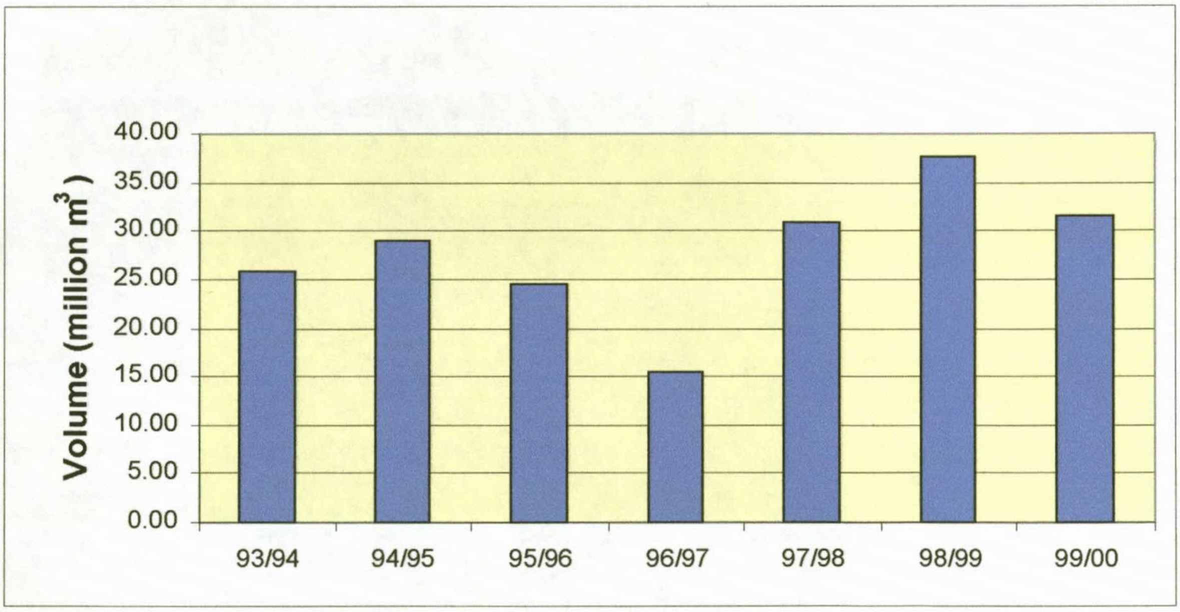

Figure 3.8: Annual water release for agricultural use (1993/94 – 1999/00)

Source: Berg River Irrigation Board (2000)

Figure 3.9 shows the highly seasonal demand for irrigation water from the Berg River. The high demand coincides with high summer temperatures, high evapotranspiration and therefore high crop demands. One of the most critical periods is the after-harvest (usually March-May) irrigations needed to enable crops to build up reserves for the next season. During years when the rainy season starts late, a shortage of irrigation water for this important period in the crop cycle is often experienced.

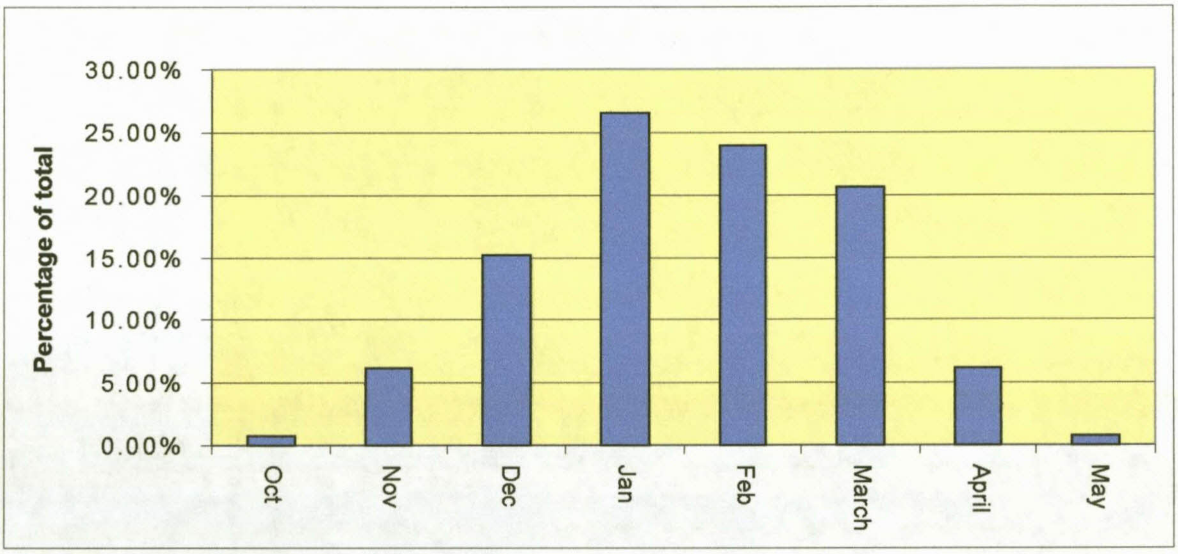

Figure 3.9: Seasonal demand for irrigation water for the Upper-Berg (1993-2000)

Source: Berg River Irrigation Board (2000)

Unfortunately there is no accurate estimate of land use available for the Upper-Berg River. Most of the statistics are either for the whole Berg River or for districts within the Berg River. The DWAF (1993c) estimated the total area under irrigation in the Upper-Berg River during 1980 at 7686.3 ha. The DWAF (2000) estimated that approximately 80 percent of the total entitlement (15 019 ha) area is used for irrigation purposes. The survey results of this study found that this percentage is closer to 82.75 percent. The total estimated area under irrigation is, according to the survey results, therefore 12 429 ha. The growth in the area irrigated since 1980 was therefore approximately 62 percent, or an average of 3.1 percent per annum. From these results it can be derived that the average growth in water demand for the agricultural sector was also approximately 3 percent per annum. However, the DWAF (1992a) indicated that growth has also slowed down since 1995 and given the uncertainties at present with regard to the future availability of water and the depressed fruit and wine markets it is expected, that at least for the near future, growth will slow down even further. The estimated crop distribution for 1999/2000 is presented in Table 3.5.

Table 3.5: Estimated crop distribution in the Berg River irrigation area (1999/2000)

Irrigation crops	Hectare	% of total
Vineyard	7245	53.0%
Table grapes	2982	24.0%
Plums	485	3.9%
Soft citrus	568	4.6%
Olives	267	2.1%
Vegetables	339	2.7%
Pears	297	2.4%
Citrus	231	1.9%
Peaches	155	1.2%
Other	529	4.3%
Total	**12 429**	**100%**

The crops presented above use approximately 38 million m^3 of water from the Theewaterskloof Dam. The percentage of water from natural runoff to fill the farm dams varies between the different irrigation areas (65 to 90 percent), as the rainfall becomes lower further away from the mountains. The survey results indicated that on average 70 percent of the capacity of the dams are filled up from natural runoff. If the DWAF (1993c) estimate of the farm dam capacity (40 million m^3) is assumed to be correct, the 12 429 ha is irrigated with 38 million m^3 from the Theewaterskloof Dam plus 28 million m^3 water from farm dams natural inflow plus 12 million m^3 winter water extraction from the river (mostly to fill up farm dams for use in the summer). This amounts to an average availability of 66 million m^3 of water or 5 310 m^3 per ha per annum.

3.4.6 Ecological demand and the reserve

According to the DWAF (1994a and 1994b) the identification of the Berg River as a significant source for the supply of fresh water to the Western Cape brought into question the consequences of abstraction from the river on the riverine ecosystem, in particular the estuary. Three possible schemes have been identified for the further exploitation of the Berg River, namely via Skuifraam Dam, Voëlvlei/Lorelei and Misverstand Dam. When implemented, these schemes could reduce the mean annual runoff below Misverstand from 700 million m^3 at present to about 270 million m^3.

According to the DWAF (2000) the ecological and reserve demand has not been estimated. Consultants were appointed by the DWAF to determine this demand but the results will not be available before 2001. The DWAF (1994a) proposed a hydrograph that specifies an annual release of a medium flood (25 million m^3) in June, a small flood (15 million m^3) in August, freshets of 5 million m^3 in July and September and a constant base flow of 0.6 m^3 per second. This release would be over and above water which would pass over the spillway. The total annual volume released (excluding the 1 in 5 year flood) would be 68 million m^3. For the purpose of this study the reserve was assumed to be 5 percent of the capacity of the Theewaterskloof Dam. According to the DWAF (1992a) the historical firm yield[2] of the Theewaterskloof Dam is 207 million m^3. It is therefore assumed that the reserve amounts to a constant monthly demand of 10.35 million m^3.

3.4.7 The water balance for water released from the Theewaterskloof Dam

A water balance for the Theewaterkloof Dam was constructed from all the information available and is summarised in Table 3.6. Although this is only a partial balance, it contains all the information relevant to this study.

Table 3.6: Water balance for the Theewaterskloof Dam (2000/2001)

User	Urban Million m^3	Irrigation Million m^3	Total Million m^3	Theewaterskloof supply Million m^3
Overberg	3.6	25	28.6	
Cape Town	120	0	120	
Upper-Berg	0	42	42	
Stellenbosch	0	11.8	11.8	
Helderberg	0	9.8	9.8	
Banhoek	0	1.8	1.8	
Other allocations	4.0	0	4	
Total	**127.6**	**90.4**	**218**	**207**

Source: DWAF (2000)

From Table 3.6 it is clear that if only the irrigation and urban allocation are considered (excluding the reserve and the ecology), the allocations from the Theewaterskloof Dam already exceed the historical firm yield of 207 million m^3. In addition to the water available

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[2] The firm yield is the volume of water that the dam can yield at 100 percent confidence.

for irrigation to the Upper-Berg River from the Theewaterskloof Dam it is estimated from the farm dam capacity, that another 12 million m^3 is extracted from the Berg River during the winter months to fill up farm dams. The natural flow of the river in the summer months is not included in these calculations but from the hydrological surveys by the DWAF (1993e) it is clear that due to the low rainfall in the summer months, it does not play an important role.

3.5 Quality of the Berg River water

According to Ellis (2000) previous studies on soil salinity in the Berg River Catchment Area indicated that soil salinity is a real problem in many areas of the catchment and that the left bank tributaries in general yielded runoffs that contained unacceptable high salt loads.

De Clercq, Gordon, Basson, Latief, Engelbrecht, Hoffmann, Ellis, Fey and De Smet (2000) pointed out that the implementation of new schemes in the Berg River will remove an additional 20 percent of fresh water from the river main stream and will lead to a strongly regulated river system between the proposed Skuifraam Dam and the Misverstand Dam. The likelihood has sparked serious concerns relating to water quality, fitness for use and ecological deterioration.

De Clercq *et al* (2000) identified the following quality-related concerns:

- Salinity problems.
- Increasing nutrient levels due to increasing volumes of treated waste water effluents and increasing non-point source loadings related to dryland and irrigated agriculture.
- The primary ecological concerns relate to the regulated character of the flow regime in the future. Releases to meet high summer irrigation demands, in themselves atypical of a winter rainfall regime, may have unacceptable low temperatures (and possible low oxygen levels).

An important principle of Integrated Catchment Management is that it cannot be sustainable without the commitment and participation of the stakeholders and the communities in a catchment. This principle applies equally to water-quality management. It is necessary on these grounds to promote an understanding of the importance of water-quality management among the communities, water users and stakeholders of a catchment. According to De

Clercq *et al* (2000) this need has both an educational and a technology transfer component, the capacity for which is still limited in the Western Cape and requires further development in an evolutionary manner. Although this study is not directly concerned with the impact of water quality on the ecology of the Upper-Berg River, the author takes note of these concerns and realises that the quality of the water source may have a major impact on the value of water for water users. However, there is not sufficient empirical data available to include quality concerns in the modelling framework for the Berg River at this point in time.

3.6 The sampling process

A farm survey was conducted to assess the resources, land use and the financial position of farmers in the Upper-Berg River. The questionnaire is shown in Appendix A.

Stratified random sampling with the unequal sampling fractions method was adopted for the survey. Stratification allows for dividing the population into subpopulations or strata that are less variable than the original population; different parts of the population can be sampled at different rates when this seems advisable. There are several reasons for choosing this method:

- Differences between the strata mean in the population does not contribute to the sampling error of the estimate of the population mean; it arises solely from variations among sampling units that are in the same stratum.
- If strata can be used to divide a heterogeneous population into parts of which each is fairly homogeneous, a substantial gain in precision over simple random sampling can be expected.
- In stratified sampling the size of sample to be taken from any stratum can be chosen separately. This freedom of choice provides scope for an efficient allocation of resources to the sampling of the strata.
- When different parts of the population present different problems of listing and sampling, stratification enables these problems to be handled separately.

The size of the total sample for all strata was calculated. The first step was to decide how large an error could be tolerated in the estimate. A five percent error was decided upon. The next step was to express the allowable error in terms of confidence limits. Suppose that L is the allowable error in the sample mean and the researcher is willing to take a 5 percent chance that the error will not be exceeded. According to Snedecor and Cochran (1982) the sample size n required to attain a given limit of error L is then $n = 4S^2/L^2$.

To use this relationship an estimate of the population's standard deviation S is required. With the Berg River this was obtained by working on the entitlement for each registered property provided by the Department of Water Affairs and Forestry (2000). With L equal to 5, the sample size was calculated to be 115 properties in order to enable an estimate of the true mean entitlement within 5 hectares, with a 5 percent risk that the error will exceed 5 ha. Table 3.7 provides a summary of the sampling exercise.

Table 3.7: Summary of the sample sizes

Region	Total ha	Number of units N_h	Mean ha per unit Y_h	Std dev S_h	N_hS_h	Relative sample rate (%) $\boxed{N_hS_h/\sum N_hS_h}$	Sample rate 115	Total per region
NAP-L	552	11	50	29	323	5.70%	7	
NAP-M	240	12	20	4	49	0.90%	1	
NAP-S	103	11	9	3	35	0.60%	1	9
Perdeberg-L	752	16	47	15	238	4.20%	5	
Perdeberg-M	376	14	27	3	43	0.80%	1	
Perdeberg-S	227	16	14	4	68	1.20%	1	7
SAP-L	521	6	87	25	151	2.70%	3	
SAP-M	221	5	44	15	77	1.40%	2	
SAP-S	52	6	9	2	14	0.20%	0	5
Berg1-L	2 224	36	62	38	1376	24.30%	28	
Berg1-M	779	40	19	2	93	1.60%	2	
Berg1-S	378	37	10	3	118	2.10%	2	32
Berg2-L	2 901	57	51	28	1607	28.40%	33	
Berg2-M	1 016	62	16	4	243	4.30%	5	
Berg2-S	448	58	8	2	97	1.70%	2	40
Berg3-L	879	12	73	25	305	5.40%	6	
Berg3-M	295	10	30	5	45	0.80%	1	
Berg3-S	249	19	13	6	119	2.10%	2	9
Riebeek-L	512	11	47	8	93	1.60%	2	
Riebeek-M	344	12	29	4	49	0.90%	1	
Riebeek-S	145	11	13	6	61	1.10%	1	4
Malmesbury-L	968	12	81	25	304	5.40%	6	
Malmesbury-M	589	15	39	3	44	0.80%	1	
Malmesbury-S	252	14	18	7	102	1.80%	2	9
Total	**15 022**	**503**			**5 653**	**100%**	**115**	**115**

L= Large, M= Medium, S = Small and a unit = one property

As has been indicated earlier the Berg River riparian farmers were divided into Berg1, Berg2, and Berg3 districts. The other four districts have privately owned irrigation board schemes. These are Suid-Agter-Paarl (SAP), Noord-Agter-Paarl (NAP), Perdeberg (PB), and Riebeek-Kasteel (RK). Riebeek-Kasteel actually consists of the Riebeek-Kasteel and the Riebeek-Wes schemes but for the purpose of the research these two were treated as one area. According to the registered entitlement areas there is also a Malmesbury-Tulbach area. The farmers in this area were combined with those of the Berg3 irrigation region in the survey.

Farms in each of the seven areas were divided into small, medium and large entitlements (strata) according to the upper third, the middle third and lower third. The intention was to draw a sample of farmers with small, medium and large entitlements. The problem however was that an irrigation area such as Suid-Agter Paarl contains only 17 properties. With a sample of 115 this means that 6 properties were to be selected from this area. The sample per region became too small to apply this approach. The other problem is that for a number of reasons (dry land cultivation, other water sources, livestock and other enterprises) the entitlements do not necessarily provide an indication of the magnitude of farming operations. It was therefore decided to abandon the idea of small, medium and large farms for sampling purposes and to conduct the survey according to the total sample size from each region as shown in Table 3.7. This would at least mean that the total sample in terms of entitlement areas is representative for the Upper-Berg River as the relative size of samples from each irrigation area was large enough to be representative of the Upper-Berg River.

3.7 Survey results

The survey results are presented in two sections. In the next section the responses of farmers to the survey are discussed. This is followed by a description of the characteristics of the irrigation regions.

3.7.1 Response of farmers to the survey

The initial reaction of farmers to the survey was disappointing. After the first attempt in November 1999, two more attempts were made during December 1999 and again in March 2000 to survey the number of properties as calculated in Table 3.7. During the last survey it became evident that farmers encouraged each other to participate and the general response was more positive. In some regions more farmers participated than was originally foreseen. However, the response from Berg1 and Berg2 remained disappointing. It was then decided that given the main purpose of this study i.e. to develop a framework to model water markets, the response was sufficient to reach the objectives. The response in each area is presented in Table 3.8.

Table 3.8: General survey information

General information	Berg1	Berg2	Berg3	SAP	NAP	PB	RK	Total
Sample size (planned)	32	39	20	5	8	7	5	115
Actual number of participants	18	24	16	5	10	7	15	95
% response	57%	62%	81%	100%	123%	100%	328%	83%
% of total sample	19%	25%	17%	5%	11%	7%	16%	100%
Planned % of sample	28%	34%	17%	4%	7%	6%	4%	100%
Total area of farm (ha)	2851	2001	5688	1354	522	2511	7114	22041
% of total participated	13%	9%	26%	6%	2%	11%	32%	100%
Total area irrigated	1315	1297	984	430	387	434	1499	6346
% of total participated	21%	20%	16%	7%	6%	7%	24%	100%
Dryland	558	241	4101	504	30	1795	4039	11267
Natural grazing	629	59	277	242	19	150	297	1672
Farmyard and odd	350	404	327	178	87	132	1259	2736
Water quota (m^3/ha)	4000	5000	6000	4000	5000	5000	6000	na
Sample entitlement (ha) summer	1161	1324	1308	400	343	273	328	5137
Sample entitlement (ha) winter	-	-	-	-	-	-	418	418
Total sample entitlement	1161	1324	1308	400	343	273	746	5555
Total entitlement	3380	4365	3233	867	969	1441	764	15019
Percentage of total entitlement	34.3%	30.3%	40%	46.1%	35.4%	18.9%	97.6%	37.0%

There were also other reasons for the deviations from the sample sizes calculated in Table 3.7:

- The response from the total sample was 83 percent. Given the sensitivity surrounding the new water bill this is regarded as an exceptionally good result.
- Some landowners own more than one farm. On arrival at some of these farms the farmers often selected the property for which it was possible, from a practical point of view, to separate the financial figures from the rest of the farm operations. This is also a reason why, in some instances, the survey results show a higher response than the original planned sample.
- In the Riebeek-Kasteel area it became clear during the survey that the variation was large and it would be more representative to survey more of the farms. Also, farmers spontaneously contacted the research team to participate in the study.

The survey covered a total farm area of about 22 000 ha of which 11267 ha are currently used for dryland farming and 6376 ha for irrigation. The irrigated area represents more than 50 percent of the estimated area under irrigation in the Upper-Berg River. The total area irrigated by the respondents represents about 37 percent of the total entitlement area of the Upper-Berg River. However, per subregion it varied between 19 percent and 97 percent of the total entitlement area.

3.7.2 Characteristics of the irrigation regions

The irrigation land use pattern of the various regions is presented in Table 3.9. It is clear that with the exception of Berg2 and NAP, wine grapes dominate all the regions. Berg2, RK and NAP are the three most important table grape producing areas. The results also show that most of the other deciduous fruits are produced in Berg1, Berg2 and to a lesser extent Berg3. In the SAP region there is virtually no diversification, with olives as the only other important crop.

Table 3.9: Irrigation land utilisation (hectares)

Irrigation	**Berg1**	**Berg2**	**Berg3**	**SAP**	**NAP**	**PB**	**RK**	**Total**	**% of total**
Vineyard	709	487	638	315	67	305	1066	3587	57.4%
Table grapes	95	497	118	-	204	70	308	1291	20.7%
Plums	126	41	16	-	47	11	-	240	3.8%
Soft citrus	48	77	21	-	27	28	8	209	3.3%
Olives	16	1	-	115	6	-	20	158	2.5%
Vegetables/melon	9	61	66	-	3	5	-	144	2.3%
Pears	129	7	1	-	-	13	-	150	2.4%
Citrus	60	2	39	-	6	3	11	122	1.9%
Peaches	55	6	-	-	17	-	23	101	1.6%
Nursery	13	10	37	-	-	-	-	60	1.0%
Tobacco	-	0	-	-	-	-	30	30	0.5%
Pastures	-	12	27	-	-	-	-	39	0.6%
Guava	-	22	4	-	-	-	-	26	0.4%
Feed grain	-	15	-	-	-	-	-	15	0.2%
Strawberries	12	22	-	-	-	-	-	34	0.5%
Spices	9	-	-	-	-	-	-	9	0.1%
Apples	9	-	-	-	-	-	-	9	0.1%
Apricots	-	4	-	-	-	-	-	4	0.1%
Avocado	1	22	-	-	-	-	-	23	0.4%
Total irrigation	**1290**	**1286**	**968**	**430**	**377**	**434**	**1466**	**6251**	**100.0%**

This is probably because the SAP region is famous for its privately owned wine cellars (as will again be pointed out in the following section). It is also clear that the combined area of wine grapes, table grapes, plums, soft citrus and vegetables represent more than 90 percent of the total irrigated area. Because of the small contribution to the total area of some of the crops e.g. avocado, apricots and apples, they were excluded from the land use pattern for purposes of the modelling exercise. Although this study is concerned with irrigation, dryland crops make an important contribution in some of the regions. Dryland farming is particularly important in the Berg3, PB, and RK regions. The utilisation of dryland is presented in Table 3.10.

Table 3.10: Dryland utilisation (hectares)

Dryland	**Berg1**	**Berg2**	**Berg3**	**SAP**	**NAP**	**PB**	**RK**	**Total**	**% of total**
Wine	60.1	54	4	10	-	-	189	317.3	4.3%
Wheat	-	-	1657	-	-	870	1985	4512	61.8%
Canola	-	-	455	-	-	-	50	505	6.9%
Korog	-	-	-	-	-	-	40	40	0.5%
Oats	-	-	225	-	-	80	127	432	5.9%
Pastures	-	-	350	-	-	-	343	693	9.5%
Lupins	-	-	40	-	-	-	-	40	0.5%
Barley	-	-	10	-	-	-	-	10	0.1%
Lucerne	-	-	-	-	-	599	-	599	8.2%
Olives	-	-	-	150	-	-	-	150	2.1%
Total dryland	60.1	54	2741	160	-	1549	2734	7298	100%

More dryland wine grapes were expected but it became clear from the survey that most of the farmers apply supplemental or optimal irrigation to their vineyards. The main dryland crops are wheat, lucerne, other pastures and canola. Olives make a relatively small contribution to the total dryland area but are regarded the highest value dryland crop.

Livestock production makes an important contribution to the profitability of dryland farming. The crop residues of wheat are one of the main components of the feed flow for the livestock enterprises. The balance of the feed flow consists of lucerne, which is grown in rotation with wheat. Although livestock production is included in the model, it is not discussed in further detail in this study. The resource and financial characteristics of the irrigation regions are presented in Table 3.11.

Table 3.11: Resource and financial characteristics of irrigation regions

Item							
Water	**Berg1**	**Berg2**	**Berg3**	**SAP**	**NAP**	**PB**	**RK**
Private dam capacity (m^3 x 1000)	2387	831	163	927	685	853	3811
Private dam capacity/ha irrigated	1815	641	165	2154	1770	1966	2543
Value attached to a water right	5639	5367	6203	5000	4730	5143	6487
Additional hectares available	495	262	1067	200	36	160	954
Labour							
Permanent labour (labourers)	464	553	225	60	335	156	488
Casual labour (labourers)	282	719	212	55	383	130	426
Total labourers (permanent + casual)	746	1272	437	115	718	286	914
Total remuneration (million)	7.6	11.9	4.2	1.3	6.6	2.0	8.3
Permanent labour per ha irrigated	0.35	0.43	0.23	0.14	0.87	0.36	0.33
Casual labour per ha irrigated	0.21	0.55	0.22	0.13	0.99	0.30	0.28
Overhead costs							
Total: labour excluded (R million)	8.3	9.3	3.0	1.2	3.3	1.6	7.9
Per ha irrigated (Rand per ha)	6305	7144	3069	2830	8425	3790	5257
Loans							
Short-term loans (R million)	6.4	14.0	8.5	1.8	6.7	3.2	12.3
Long + Med. term loans (R million)	12.1	11.8	9.9	0.7	3.1	1.0	9.9
Total debt (R million)	18.5	25.7	18.4	2.5	9.7	4.2	22.2
Total debt per ha irrigated (Rand)	14053	19834	18698	5797	25124	9709	14800
Total debt per ha farmed (Rand)	6480	12858	3235	1843	18618	1678	3118
Property valuation per ha farm (Rand)							
Value of land	68652	101286	25937	46994	70014	33926	29230
Value of fixed improvements	33439	40000	16008	5820	32695	12123	7311
Value of implements, machinery, other	14414	12383	5963	3560	16036	3888	5641
Value of livestock	3	293	265	-	-	296	389
Value of stocks	3309	19	52	-	167	351	1925
Total value of property	119816	153981	48225	56374	118912	50585	44496
Debt as percentage of assets	5.4%	8.4%	6.7%	3.3%	15.7%	3.3%	7.0%
Property valuation per ha irrigated (rand)							
Value of land	104557	120478	72481	105774	84367	91889	76223
Value of fixed improvements	23387	51443	21641	20586	32284	34445	19515
Value of implements, machinery, other	12316	15343	16368	10016	15869	11221	15452
Value of livestock	18	446	1831	-	-	3021	1786
Value of stocks	1218	46	151	-	258	1025	4279
Total value of property	141497	187757	111082	136375	132779	141602	117256
Total investment	186	244	109	59	51	61	176
Type of irrigation as percentage of total irrigation area (%)							
Sprinkle and other	27.6	26.6	34.3	71.9	13.7	16.7	7.9
Micro	36.9	22.2	28.0	28.1	66.0	44.8	12.5
Drip	34.8	51.1	36.6	-	20.2	38.5	79.6
Irrigation as % of total farm	46.1	64.8	17.3	31.8	74.1	17.3	21.1

The most important findings from the survey results are the following:

- Although the dam capacity figures are not very accurate it is clear that with the exception of Berg1, the farmers on the private irrigation board schemes (SAP, NAP, PB and RK) have the largest dam capacities. Farmers on these schemes need the dams to ensure that they get their full entitlements during the October to March season and also for security reasons in the event of a breakdown of the pumping system. The large farm dam capacity in Berg1 is also due to historical reasons. This is the oldest irrigation region; irrigation farming started long before there were any government irrigation schemes existed and farmers had to rely on dams.
- The permanent labour force employed by the respondents consists of approximately 2 281 labourers and the casual labour of 2 207 (converted from labour days). The number of labourers per ha varies quite substantially between areas. However, it is clear that NAP uses the largest amount of labour per ha as a result of the predominant table grape enterprise in the area.
- During the survey it became evident that farmers perceive the new labour laws as very farmer-unfriendly. During the last few years, farmers tended to invest in labour-saving technologies. They also make more use of contract labour teams. These teams often consist of labourers who were previously employed by farmers on a permanent basis. The survey also pointed out that in general the housing of the labourers in the study area is of a high standard. Most of the houses are two to three bedroom houses with a kitchen and bathroom with hot water. In many instances, especially on the larger farms, the farm also provides entertainment facilities as well as care centres for small children. Farmers also provide free electricity and transport to the towns.
- The total amount of capital invested in the survey area is approximately R886 million. Therefore, for every one million Rand invested about 5 job opportunities (permanent labour equivalent) are directly created on farm level. This figure can probably be more than doubled if the rest of the marketing chain (packaging, transport and handling in the harbour) is taken into consideration. Although this is only a casual observation and not scientifically based, this information is very important from a social welfare point of view.

- The average value per ha irrigated farm is about R140 000 compared to about R85 000 per ha of the total farm area. However, there are large variations between the regions with the highest investment per ha farm and ha irrigated in the Berg2 region (close to or in the municipal area of Paarl or Wellington) and the lowest in the Berg3 region (large farms and predominantly dryland). The reason for the relatively high capital investment in the NAP region is the prevalence of the highly valued predominantly table grape enterprise in this area. Where the margin between the per ha total farm figure and per ha irrigated figure is small (Berg 1, Berg 2, NAP), farms are predominantly irrigation farms.
- It is clear that there is a high correlation between overhead costs and the capital investment. Berg 1, Berg 2 and NAP have the highest overhead costs and also the highest capital investment per ha farm.
- The short-term liabilities (overdraft) figures are not very accurate as farmers were reluctant to provide this data. However, they were prepared to provide the maximum overdraft that they can obtain from financial institutions. The assumption was made that on average overdrafts are 50 percent of the maximum at an interest rate of 17 percent. The long plus medium term liabilities are more accurate. It is clear that the table grape industry, especially NAP, made considerable capital investments during the last couple of years and this is probably the reason why NAP has the highest overall debt per ha irrigated.
- Also significant is the value that the farmers attach to a water right. It is clear that the value of a water right increases towards the dryer areas (RK and parts of Berg 3). It is also significant to note that the value that the non-riparian users (SAP, PB and NAP with the exception of RK) attach to the water is more or less the same (R5 000). The reason for this is that most of these schemes already operate at close to 100 percent capacity. In some instances the system cannot even deliver enough water for the farmers at the bottom end to receive their full allocation. Although these farmers are entitled to say 4 000 m^3 per ha the irrigation scheme can for example only deliver 3 600 m^3.
- Berg3 and RK (larger farms) have the highest potential for irrigation expansion if they can obtain more water rights. This is also reflected in the value that they attach to a water right.
- Table 3.11 shows clearly that irrigation farmers in the Upper-Berg River are already using efficient irrigation systems. Although this varies between regions, 28.7% of

the hectares are under drip (95% efficient) and 44.2 % under micro jet irrigation (85% efficient). Therefore on average 73% of the total area irrigated is already under efficient irrigation systems and farmers do not have much scope for improvement in this respect. It must also be borne in mind that drip and micro irrigation systems cannot be utilised for all soil types. Furthermore there are substantial differences between the regions. At present, SAP predominantly still uses sprinkle irrigation (only 75% efficient) whereas NAP has predominantly micro-jet systems and RK drip systems. It is concluded that in the driest region (RK) the predominant irrigation system is drip, which is the most efficient.

- Table 3.11 also points out that Berg1, Berg2 and NAP are the areas where the irrigation farming intensity, measured by the irrigation area as percentage of total farm area, is the highest.

The survey clearly indicated substantial differences between the irrigation areas with regard to farm size, land use, costs and irrigation systems. This will play an important role in the simulation of a water market as these factors may play an important role in the marginal value of water for different water use regions.

3.8 Typical farms

Because of the large differences between individual farms it would not make much sense to use averages as criteria for creating representative farms for an area. It will be more realistic to create typical farms for each area. The end result must be a farm that is representative for a specific area in terms of land utilisation, debt and capital investment. The survey data were used to establish the variance within a region, in order to decide on the number of typical farms per region. A large variance in area irrigated and land use led to the construction of more typical farms per region. Twenty typical farms were thus constructed within the 7 irrigation regions. In order to simplify the discussion of the typical farms within each region the name of the region will be stated first, followed by a dot and then the number of the typical farm. For example, Berg1.1 represents region Berg1 with typical farm 1. This notation will be used throughout the study. The typical farms are discussed in two sections. The riparian farmers are presented first, followed by the typical farms on irrigation board pump schemes.

3.8.1 Typical farms in the riparian regions

The typical farms in the Bergl, Berg2 and Berg3 regions are all typical riparian farmers. They are discussed in the following three sections.

3.8.1.1 The Bergl region

The large variance between farms in the Bergl region and the need to compensate for the relative low survey response rendered it necessary to construct 6 typical farms:

- Bergl.1: A farm smaller than 25 ha with table grapes as dominant crop
- Bergl.2: A smaller than 25 ha mixed fruit farm
- Bergl.3: A farm smaller than 25 ha with vegetables as dominant crop
- Bergl.4: A mixed fruit farm between 50 and 100 ha
- Bergl.5: A wine farm between 50 and a 100 ha
- Bergl.6: A mixed fruit farm larger than 100 ha

The resource and financial characteristics of the farms are presented in Table 3.12. Berg 1.4 to Bergl.6 represents more than 90 percent of the irrigated area. However, in order to include the smaller farms in the region, three typical small farms were constructed (Bergl.1 to Bergl.3). Most of the typical farms already use their full entitlement, or close to it, when entitlement is compared to the irrigated area. Farm dam capacity plays an important role on the Bergl.3 and Berg 1.6 typical farms.

Furthermore, it is important to note that the region has almost reached full development, as there is not a large area left for development. It is also clear that the table grape enterprise is relatively labour intensive. Bergl.1 uses almost twice as many labourers compared to Bergl.2 which has almost the same amount of irrigated area.

The overhead costs and loans per ha irrigated land are much higher on the smaller typical farms. It is also clear that farms with table grape enterprises are generally valued higher than the other farms, with the exception of Bergl.3, where vegetables are produced. The vegetable industry is also a high capital input, high-value, specialised industry.

Table 3.12: Resource and financial characteristics of typical farms in Bergl

Item	**Bergl.1**	**Bergl.2**	**Bergl.3**	**Bergl.4**	**Bergl.5**	**Bergl.6**
General information						
% of irrigation area	4%	3%	2%	18%	19%	53%
Total area of farm (ha)	33	27	18	99	134	480
Total area irrigated (ha)	22	21	13	60	59	162
Dryland (ha)	-	-	-	4	9	50
Natural grazing (ha)	-	1	-	17	1	-
Farmyard and odd (ha)	5	4	5	8	9	16
Water quota (m^3/ha)	4000	4000	4000	4000	4000	4000
Entitlement:summer (ha)	20	24	14	55	68	139
Entitlement:Winter (ha)	-	-	-	-	-	-
Total entitlement (ha)	20	24	14	55	68	139
Resources						
Dam capacity/ha irrigated	1136	637	5725	924	482	2778
Additional area available (ha)	-	-	1	17	54	-
Permanent labour (labourers)	13	15	12	23	25	80
Casual labour (labourers)	31	6	14	4	3	28
Total labourers	44	20	26	27	28	108
Permanent labour per ha irrigated	0.59	0.68	0.92	0.39	0.41	0.49
Casual labour per ha irrigated	1.40	0.26	1.07	0.07	0.06	0.17
Overhead costs per ha irrigated (Rand)						
Excluding installments on loans	11364	9026	17073	4002	2723	4330
Including installment on loans	13580	10932	32417	4712	4612	6374
Loans per ha (Rand)						
Total debt per ha irrigated	15909	11211	72519	3269	2519	11780
Total debt per ha farmed	10606	8945	53221	1965	1116	3976
Valuation per ha irrigated (Rand '000)						
Value of land	106.2	115.9	79.5	81.0	107.8	109.3
Value of fixed improvements	77.3	32.7	58.2	29.4	33.8	15.4
Value of implements, mach, other	19.8	18.0	75.9	14.2	6.7	8.0
Value of livestock	-	-	-	-	-	-
Value of stocks	9.1	0.5	26.7	-	-	-
Total value of property	197.1	167.1	240.3	178.5	150.5	118.7
Debt as percentage of assets	8%	7%	30%	2%	2%	10%
Household expenses (Rand '000)	70	75	50	100	100	150

However, the land values in this part as well as Berg2 are highly distorted as a result of their location near to Franschhoek and Paarl. Some of the smaller farms possess historical buildings, valued at millions of Rands, and belong to wealthy foreign owners. Table 3.13 shows the irrigated land use of typical farms in the Berg1 irrigation region. The deviation between the total irrigated area in Table 3.12 and Table 3.13 came about because some respondents did not include fallow areas (or areas to be re-established). Table 3.13 points at an overwhelming predominance of wine farming in region Berg1. Dryland crops are not common in the Berg1 region.

Table 3.13: Irrigated land use of typical farms in Berg 1

Crop	**Berg1.1**	**Berg1.2**	**Berg1.3**	**Berg1.4**	**Berg1.5**	**Berg1.6**
Vineyard	-	-	4	15	43	123
Table grapes	15	7	-	6	4	-
Plums	-	-	-	10	1	24
Soft citrus	4	7	-	4	-	-
Olives	-	6	-	-	2	-
Vegetables	-	-	9	-	-	-
Pears	-	-	-	12	-	20
Citrus	2	4	-	10	1	-
Peaches	-	-	-	3	2	6
Total irrigation	**21**	**24**	**14**	**60**	**52**	**173**

3.8.1.2 The Berg2 region

Three typical farms represent the Berg2 region, including a predominantly wine grape farm (Berg2.1), a mixed fruit farm (Berg2.2) and a wine/table grape farm (Berg2.3). The farms represent respectively 17.3, 20.7 and 62.1 percent of the total irrigated area in the Berg2 region. Table 3.14 provides the most important physical and financial characteristics of the farms.

Table 3.14: Resource and financial characteristics of typical farms in Berg2

Item	**Berg2.1**	**Berg2.2**	**Berg2.3**
General information			
% of irrigation area	17%	21%	62%
Total area of farm (ha)	46	65	136
Total area irrigated (ha)	32	30	101
Dryland (ha)	8	9	13
Natural grazing (ha)	-	3	4
Farmyard and odd (ha)	7	23	19
Water quota (m^3/ha)	5000	5000	5000
Entitlement: summer (ha)	32	34	99
Entitlement: winter (ha)	-	-	-
Total entitlement (ha)	32	34	99
Resources			
Dam capacity/ha irrigated	563	1398	655
Additional area available (ha)	9	-	15
Permanent labour (labourers)	11	17	39
Casual labour (labourers)	3	32	45
Total labourers	14	49	84
Permanent labour per ha irrigated	0.34	0.57	0.39
Casual labour per ha irrigated	0.10	1.09	0.45
Overhead costs per ha irrigated (Rand)			
Excluding instalment on loans	3909	9325	7153
Including instalment on loans	8706	11606	8169
Loans per ha			
Total debt per ha irrigated	17823	23870	16342
Total debt per ha farmed	12279	10930	12069
Valuation per ha irrigated (R '000)			
Value of land	63.3	121.4	96.9
Value of fixed improvements	31.3	33.5	49.3
Value of implements, mach, other	11.9	16.7	10.1
Value of livestock per ha	-	-	-
Value of stocks per ha	-	-	-
Total value of property per ha	121.6	167.7	153.6
Debt as percentage of assets	15%	14%	11%
Household expenses (R '000)	80	80	120

All the farms have dam storage capacity but at Berg2.2 farm dam capacity plays a more important role than on the other farms. Table grape production is an important enterprise on Berg2.3. This explains the relative high labour use. Table 3.15 shows the land use of the three typical farms for region Berg2. Whilst there are no dryland crops in the Berg1 region, Berg2.2 and Berg2.3 have small areas under dryland vineyards. All the typical farms use their full entitlement of water.

Table 3.15: Land use of typical farms in Berg 2

Crop	Berg2.1	Berg2.2	Berg2.3
Irrigation			
Vineyard	25	7	33
Table grapes	1	6	55
Plums	0	4	2
Soft citrus	0	8	2
Vegetables	3	5	5
Pears	-	-	1
Peaches	-	1	-
Guava	1	-	2
Total irrigation	**31**	**31**	**100**
Dryland			
Wine	-	4	2
Total dryland	-	**4**	**2**

Although Berg2.2 does not have the largest area under table grape production, the value per ha irrigated land is the highest. This farm is slightly more diversified than Berg2.3 (wine/table grapes). During the survey it became clear that farmers value diversification much higher than in the past. The reason for this is that they have to compete in a highly competitive export market and diversification is an important way to reduce risk.

3.8.1.3 The Berg3 region

Four typical farms represent the Berg3 region. In this region dryland agriculture plays a more important role than in the Berg1 and Berg2 regions. Table 3.16 presents the most important resource and financial characteristics of the typical farms in Berg3.

The typical farms in Berg3 are Berg3.1, a smaller than 50 ha wine farm; Berg3.2 a smaller than 50 ha table grape farm; Berg3.3 a larger than 50 ha wine-mixed fruit farm, and Berg3.4 a larger than 50 ha wine/table grape farm. Respectively they represent 13.7, 11.0, 52.6 and 22.8 percent of the total irrigated area for the Berg3 irrigation region. Table 3.16 shows that there is more land available that can be developed for irrigation. The entitlements on all the typical farms are larger than the irrigated area. This is also one of the areas where farmers face expropriation of existing water rights if they cannot prove by 2001 that they use their water rights beneficially. During the survey it became evident that most of the farmers bought their water rights at costs ranging from R1 300 to R1 500 in the early 1990s for later development. The uncertainty about their future water rights and a depressed international market for most fruit types and low quality wine, have slowed down development in this region.

Table 3.16: Resource and financial characteristics of the typical farms in Berg3

Item	Berg3.1	Berg3.2	Berg3.3	Berg3.4
General information				
% of irrigation area	14%	11%	53%	23%
Total area of farm (ha)	276	310	270	650
Total area irrigated (ha)	34	22	129	75
Dryland (ha)	232	248	91	524
Natural grazing (ha)	2	21	36	7
Farmyard and odd (ha)	9	20	14	45
Water quota (m^3/ha)	6000	6000	6000	6000
Entitlement: summer (ha)	50	34	151	112
Entitlement: winter (ha)				
Total entitlement (ha)	50	34	151	112
Resources				
Dam capacity/ha irrigated	0	0	0	712
Additional area available (ha)	21	25	65	50
Permanent labour (labourers)	9	7	24	17
Casual labour (labourers)	6	24	11	13
Total labourers	14	31	35	30
Permanent labour per ha irrigated	0.25	0.32	0.18	0.23
Casual labour per ha irrigated	0.17	1.13	0.09	0.17
Overhead costs per ha irrigated (Rand)				
Excluding instalments on loans	3156	5394	3104	1524
Including instalments on loans	5581	7690	5825	5150
Loans per ha				
Total debt per ha irrigated	10112	12269	17909	8036
Total debt per ha farmed	1230	854	8586	923
Valuation per ha irrigated (R '000)				
Value of land	78.4	92.6	60.0	77.5
Value of fixed improvements	28.6	46.3	14.1	17.5
Value of implements, mach, other	16.6	18.2	9.0	12.0
Value of livestock	0.0	0.6	0.0	4.8
Value of stocks	0.0	0.0	0.1	0.0
Total value of property	127.4	161.5	82.8	109.4
Debt as percentage of assets	8%	8%	22%	7%
Household expenses (R '000)	80	70	140	100

However, at present some farmers appear to plant any crop (mostly short-term crops) just to prove that they use the water beneficially. Although this observation was only arrived at casually while conducting the survey and through discussions with irrigation experts in the area, it is a very important observation. Ironically one of the main objectives of the new Water Act (1998), is to promote more efficient water use for all water users. However, the fact that farmers know that they are going to loose their water rights if they do not use it has become an important cause of gross inefficiencies in irrigation water use. If the farmers' present water rights were protected by law and transferable, farmers would probably have temporally transferred their water use rights to other uses. This could do much to alleviate the looming water shortages facing the greater Cape Town area. Farm dam capacity does not play an important role in this region. Irrigation is done directly from the river. Berg3.3 and Berg3.4 show a surprisingly low labour use relative to the irrigated area. The reason for this is that to a large extent they make use of contract labour (not casual labour). This is a relative new tendency in the deciduous fruit and wine sector and according to the farmers, a consequence of farmer-unfriendly labour laws. Contract labour teams are contracted to do specific production tasks such as pruning or harvesting. It is important to bear this in mind when calculating the social impact of water reallocation from agricultural to urban use because the loss of job opportunities for contract labourers will not be reflected within the modelling framework of this study. Table 3.16 shows that capital investment in implements, machinery and other equipment on a per ha irrigated basis is higher on the smaller irrigation farms. Table 3.17 presents the land use of typical farms in the Berg3 region. It is clear that dryland cultivation plays a more important role on the smaller irrigation farms. The most dominant dryland crops are wheat and canola. Pastures constitute the most important dryland activity in Berg 3.4

Table 3.17: Land use on typical farms in region Berg3

Crop	Berg3.1	Berg3.2	Berg3.3	Berg3.4
Irrigation				
Vineyard	25	-	95	54
Table grapes	-	16	4	7
Plums	3	1	-	-
Soft citrus	-	2	2	-
Olives	-	-	6	-
Vegetables	2	-	15	-
Citrus	-	-	8	2
Pastures	1	2	-	5
Guava	-	-	-	1
Total irrigation	**30**	**22**	**130**	**69**
Dryland				
Wine	-	1	-	-
Wheat	161	118	50	42
Canola	75	16	-	25
Korog	-	-	-	-
Oats	-	22	18	15
Pastures	-	20	-	117
Lupins	-	10	-	13
Barley	-	-	-	3
Total dryland	**236**	**187**	**68**	**215**

3.8.2 Typical farms on irrigation board pump schemes

The resource and financial characteristics of the typical farms on the irrigation board pump schemes are presented in Table 3.18 and the land use in Table 3.19. Discussion is conducted under separate headings for the Suid-Agter Paarl (SAP), Noord-Agter Paarl (NAP) and Riebeek Kasteel (RK) regions.

Table 3.18: Resource and financial characteristics of the typical farms in Berg3

	SAP1.1	**SAP1.2**	**NAP**	**PB**	**RK1.1**	**RK1.2**	**RK1.3**
General information							
% of irrigation area	73	27	100	100	11	24	65
Total area of farm (ha)	226	450	52	359	402	231	611
Total area irrigated (ha)	79	115	39	62	35	88	162
Dryland (ha)	55	285	3	256	282	87	255
Natural grazing (ha)	61	-	2	21	-	5	38
Farmyard and odd (ha)	32	50	9	19	40	28	156
Water quota (m^3/ha)	4000	4000	5000	5000	6000	6000	6000
Entitlement: summer (ha)	76	96	34	39	9	20	25
Entitlement: winter (ha)	-	-	-	-	20	19	36
Total entitlement (ha)	76	96	34	39	29	39	61
Resources							
Dam capacity/ha irrigated	1744	1892	1770	1984	2571	2691	2072
Additional area available (ha)	-	150	3	20	10	30	63
Permanent labour (labourers)	14	6	22	21	24	21	34
Casual labour (labourers)	5	37	27	15	7	31	20
Total labourers	19	43	49	36	31	51	54
Permanent labour per ha irrigated	0.17	0.05	0.57	0.34	0.69	0.23	0.21
Casual labour per ha irrigated	0.07	0.32	0.69	0.24	0.20	0.35	0.13
Overhead costs per ha irrigated (Rand)							
Excluding instalments on loans	2713	3130	8469	3625	7884	6491	3105
Including instalments on loans	3085	4239	13156	5466	12899	10234	4567
Loans per ha (Rand)							
Total debt per ha irrigated	5533	6522	14397	9709	25143	14241	7523
Total debt per ha farmed	1930	1667	10669	1678	2189	5452	1997
Valuation per ha irrigated (Rand '000)							
Value of land	117.3	77.8	69.3	108.1	65.1	88.7	61.7
Value of fixed improvements	19.0	13.0	31.0	29.0	21.4	18.5	15.4
Value of implements, mach, other	6.9	11.7	15.8	9.7	24.3	17.8	12.3
Value of livestock per ha	-	-	-	1.0	2.9	0.8	1.1
Value of stocks per ha	-	-	-	-	-	4.2	0.1
Total value of property per ha	143.2	102.5	124.4	147.0	114.6	144.3	93.7
Debt as percentage of assets	4	6	12	7	22	10	8
Household expenses (Rand '000)	100	110	85	90	750	100	150

The typical farms on the irrigation board pump schemes are more restricted regarding their irrigation activities because of additional pump capacity restrictions of the schemes.

Table 3.19: Land use on typical farms in irrigation board pump schemes

Crop	SAP1.1	SAP1.2	NAP	PB	RK1.1	RK1.2	RK1.3
Irrigation							
Vineyard	79	0	7	44	20	70	118
Table grapes	-	-	20	10	12	9	31
Plums	-	-	5	2	-	-	-
Soft citrus	-	-	3	4	0	0	1
Olives	0	115	2	1	0	0	3
Vegetables	-	-	0	-	0	0	0
Pears	-	-	-	2	-	-	-
Citrus	-	-	1	-	0	0	2
Peaches	-	-	2	0	0	0	2
Tobacco	-	-	-	-	0	0	0
Total irrigation	**79**	**115**	**39**	**62**	**32**	**78**	**157**
Dryland							
Wine	3	0	-	0	8	30	5
Wheat	0	0	-	124	235	20	122
Canola	0	0	-	0	8	0	0
Korog	0	0	-	0	10	0	0
Oats	0	0	-	11	24	0	1
Pastures	0	0	-	0	0	0	57
Lucerne	0	0	-	86	-	-	-
Olives	0	150	-	-	-	-	-
Total dryland	3	150	0	221	285	50	185

3.8.2.1 The Suid-Agter-Paarl (SAP) region

The SAP irrigation scheme extracts water through a pumping system on the farm Kuilenhof situated east of Paarl near the R45 road to Franschhoek. The capacity of the pump is 200 litres/second for six months of the year, starting October and ending in March. The scheme provides water to 22 farmers.

Two typical farms represent the SAP region. SAP1 is a wine farm and SAP2 an olive farm. Both these farms are relatively large. Wine farming is the dominant enterprise in this region. SAP1 represent 73.3 percent and SAP2, 26.7 percent of the total irrigated area in this region. The farmyard and odd area is relatively large on typical farms in this region. This is because the SAP region surrounds the Paarl Mountain, of which relatively large areas are unsuitable for cultivation. The SAP region is well known for good quality wines, including some well-known wine estates.

Table 3.18 shows additional areas available for development. However, a large part of the area indicated as additional land is currently under dryland olive production. Although there are unused water rights, the capacity of the SAP irrigation scheme is fully utilised and farmers experience problems getting their full entitlement delivered on the farm. A small area of wine grapes is under dryland cultivation. Farm dam capacity is important on this scheme. Most of the dams are balancing dams with an almost constant inflow and outflow during the season and with a small spare capacity, to reduce the risk of a downtime of the scheme due to equipment failure.

The high amount of labour usage per ha on SAP2 shows the olive enterprise to be very labour intensive. The relatively high total property value per irrigated hectare at SAP1 results from the fact that most wine farms in the SAP region have their own wine cellars. The solvency relation of both these farms are healthy with debt representing less than 6.5 percent of assets.

3.8.2.2 The Noord-Agter-Paarl (NAP) region

The NAP irrigation scheme extracts water from the Berg River at a point approximately 2 kilometres north of Paarl. The water is pumped into the Noord-Agter Paarl Dam, from where it feeds the scheme with a pump with a delivery capacity of 285 litres per second. The scheme provides water to 48 farmers. The NAP irrigation scheme is predominantly a table grape-mixed fruit farming region with very little variation in the size and land use patterns. Only one typical farm represents the region.

The irrigated area of the representative farm is 39 ha and the entitlement 5000 m^3 for 34 ha (Table 3.18). A larger area than the entitlement is irrigated. This may be indicative of efficient water usage. This corresponds with Table 3.11 which shows that 80 percent of the total area is either under drip or micro irrigation with high efficiency levels. No dryland crops are produced in this region. Table 3.18 indicates that the farms on the NAP scheme are, similar to SAP, also highly dependent on dam capacity due to the same reasons. The farming operations on this typical farm are labour intensive due to the mixed fruit and table grape enterprises. The relatively high overhead costs and liabilities per ha also give an indication of the structural changes away from vineyards towards table grapes and other fruits during the last few years.

The total value of the property per ha irrigation is a fair reflection of the value of mixed fruit farms for the area.

3.8.2.3 The Perdeberg (PB) region

The Perdeberg irrigation scheme extracts water from the Berg River on the farm Haaskraal north-west of Wellington. The scheme is supplied by a main pump with a capacity of 370 litres per second during the six month season starting from October and ending in March. In addition to the main pump, there are 12 booster pumps which supply 61 farmers with irrigation water. The PB region is predominantly a wine-producing region (70 percent of the area) but table grapes (16 percent) and to a lesser extent fruit and vegetables are also produced. Because of the homogeneity of this area only one typical farm was constructed. The area irrigated on this typical farm is 62 ha. However, the entitlement is only 39 ha, indicating that farmers have their own storing capacity in dams (see Table 3.18) and that they have highly efficient irrigation systems. Table 3.11 shows that approximately 40 percent of the irrigation systems are under drip, 45 percent micro and the remaining 15 percent under sprinkle irrigation.

Farmers in the PB region also farm with dryland crops and livestock. The main dryland crops are wheat, oats and lucerne. Lucerne is also used as a rotation crop with vineyards. All the crops being cultivated in this region are labour intensive. The value of the property also shows a high capital investment in irrigation infrastructure. The PB region is in the forefront with regard to volumetric measuring of the exact volume of water they extract from the river. The solvency of the typical farm is healthy with liabilities measuring only 7 percent of assets.

3.8.2.4 The Riebeek-Kasteel (RK) region

The Riebeek-Kasteel region consists of three irrigation board schemes. The Riebeek-Kasteel (RK) scheme serves 12 farms, Riebeek-Wes Sub-district 1 (RW1) serves 4 farmers, and Riebeek-West Sub-district 2 (RW2) serves 18 farms. The three schemes therefore supply water to 34 farm units. Water is extracted from three extraction points in the river. The RK scheme extracts water from the Berg River from a farm Vleesbank situated east of Riebeek-Kasteel, RW2 from the farm Bellvue also east from Riebeek-Kasteel and RW1 from a point in the river close to Zonquasdrift. Zonquasdrift represents the border between the Upper and Lower Berg River.

The areas served by the three schemes are adjacent and are relatively homogeneous with regard to natural resources but very heterogeneous with regard to farm size and to some extent crop combinations. For model simplicity the three schemes were combined into one irrigation region, called Riebeek-Kasteel (RK), and three typical farms were constructed for the region. A weighted average pump capacity for the three schemes was calculated to be 300 litres per second. The general characteristics of the farms are presented in Table 3.18. RK1.1 represents a small wine farm with a relative large area under dryland cultivation, RK1.2 a medium-sized wine farm with a relatively small dryland component and RK1.3 a large wine farm with fruit enterprises and a relative small dryland component.

Table 3.18 shows that the area irrigated is much larger than the entitlement, suggesting the availability of other water sources. The RK region also has an important dryland farming and livestock component. Wheat, wine grapes, oats, canola and pastures are the main dryland enterprises. The pastures and crop residues (stubble land) are being utilised by sheep and cattle.

Of all the irrigation regions the RK region representative farms have the largest dam capacities. Table 3.18 shows that more than 50 percent of the water entitlement consists of winter water. The scheme pumps water in the winter to fill up the storage capacity and supplement this water in the summer with the summer entitlement. RK is the only irrigation board scheme with a winter entitlement. Winter water is being pumped from 1st of May to the 30th of September and summer water from the 1st of October till the 30th of April.

The value of livestock per ha indicates the importance of the livestock enterprise. Although this study is concerned with irrigation water use and not with dryland or livestock agriculture, whole farm models are used to represent the agricultural sector.

3.9 Crop enterprise budgets

Enterprise budgets were constructed for the various farm enterprises in the river. Although the basic production costs of crops do not vary substantially between the different areas, there are substantial differences in yield and quality. Time and budget constraints precluded the construction of individual enterprise budgets for every typical farm. This would have meant approximately 3 000 budgets. Instead, a base budget was constructed for each enterprise (49 budgets) in the Upper-Berg River.

For the perennial crops an average of 4 budgets (establishment, year 2-4, year 5-7, and mature) were constructed, increasing the total number of budgets to 88. The budgets were thereafter adapted with scaling factors calculated with data from the survey and through the input of crop and irrigation specialists to be representative for a specific region. Where applicable, the irrigation crop budgets also provide that farmers can use either optimal, supplemental or deficit irrigation strategies for short-term water shortages. The abbreviations used in the budget data are shown in Table 3.20. These abbreviations will also be used when model results are discussed.

Table 3.20: Budget information abbreviations

Description	Abbreviation	Description	Abbreviation
Irrigation red wine	IRwine	Irrigation white maize	IWmze
Irrigation white wine	IWwine	Irrigation pumpkin	IPump
Irrigation table grapes	ITable	Irrigation butternut	IButter
Irrigation plums	IPlum	Irrigation gem squash	ISqua
Irrigation soft citrus	ISoftc	Irrigation potatoes	IPotat
Irrigation citrus	ICitr	Irrigation sweetpotatoe	ISwpot
Irrigation lemons	ILem	Irrigation peppers	IPepp
Irrigation olives	IOliv	Irrigation Lucerne	ILucer
Irrigation pears	IPear	Dryland red wine	DRwin
Irrigation peaches	IPeach	Dryland white wine	DWwin
Irrigation nectarines	Inect	Dryland wheat	DWhea
Irrigation apricots	IAppr	Dryland canola	DCanol
Irrigation guavas	IGuav	Dryland korog	DKorog
Irrigation cauliflower	ICauli	Dryland oats	DOats
Irrigation cabbage	ICabag	Dryland pastures	DPast
Irrigation broccoli	Ibroc	Dryland lupine	DLup
Irrigation carrots	ICarrot	Dryland barley	DBarl
Irrigation tomatoes	ITom	Dryland lucerne	DLucer
Irrigation green beans	IGrenb	Dryland potatoes	DPotat
Irrigation green peas	IGrenp	Dryland olives	DOlive
Irrigation cucumbers	ICucm	Dairy	Dairy
Irrigation salads	ISalad	Sheep	Sheep
Irrigation beetroot	IBeetr	Beef cattle	Cattle
Irrigation sweet melon	ISpasp	Establishment	Est.
Irrigation water melon	IWatle	Year	Y
Irrigation sweet corn	ISwetc		

3.9.1 Long-term crop budgets

Table 3.21 summarises the most important budget coefficients with regard to the long-term crops. Although budgets were compiled for establishment, young, medium aged and mature trees, Table 3.21 shows the information only for mature trees. Local-1 is produced for the local fresh market and local-2 is produced for processing. The export price is a weighted average price for two export classes (where applicable). The price is the three-year average farm gate price after deduction of marketing costs such as market agent commission, shipping costs etc.

When the yield unit is indicated as "unit", it means the unit in which the crop is normally marketed. For instance the normal local-1 and export market unit for plums is a 2.5 kg carton and for table grapes a 4.5 kg carton. The local-2 market (processing) unit is ton. Fruit crop yields can vary substantially between years. A long-term average yield is used in these budgets. The model provides for deviations in gross margins over a six-year period. This will be discussed later. Table 3.21 shows that, table grapes, plums, olives and red wine have the highest gross margins. However, market risks are not included. Most of the high-value crops are also high-risk crops. Citrus, pears and apricots have the lowest water use efficiency if measured in terms of the gross margin per volume of irrigation water. Red wine, plums, and olives have the highest output per volume of irrigation water.

Table 3.21: Long-term crop budget information in Rand/ha (2000)

Crop	% of total trees	Direct Costs	Yield unit	Yield local 1	Price local 1	Yield local 2	Price local 2	Yield export	Price export	Gross income	Gross margin	Water use m^3/ha	GM per m^3
IRwine	65%	-4172	Ton	12	4500	0.0	0.0	0.0	0.0	54000	49828	6900	7.2
IWwine	65%	-4558	Ton	20	1500	0.0	0.0	0.0	0.0	30000	25442	6900	3.7
ITable	56%	-44407	Unit	400	11.4	450.0	2.0	3800	25.4	101774	57367	9800	5.9
IPlum	61%	-45154	Ton	1.2	1540	3.4	1500	18.0	5396	103654	58500	8590	6.8
ISoftc	59%	-43681	Ton	5.2	500	4.8	200	30.0	1650	53060	9379	13700	0.7
ICitr	59%	-42807	Ton	12.6	500	7.8	300	36.0	1100	48240	5433	14780	0.4
ILem	56%	-88740	Ton	14.4	750	5.6	100	60.0	1700	113360	24620	14780	1.7
IOliv	44%	-4957	Ton	2.7	5000	0.1	2200	5.2	7500	52776	47819	7150	6.7
IPear	41%	-47011	Ton	5.5	1500	9.0	450	16.0	2500	52300	5289	8590	0.6
IPeach	49%	-50573	Ton	2880	7	1.8	250	3600	16	78210	27637	8590	3.2
INect	61%	-44251	Unit	1600	13	3.5	350	1900	22	63825	19574	8590	2.3
IAppr	28%	-45515	Ton	12.0	1150	0.0	0	18.0	2000	49800	4285	8590	0.5
IGuav	48%	-13470	Ton	18	800	18.0	800	0.0	0.0	28800	15330	8590	1.8
DRwin	65%	-2712	Ton	7	4500	0.0	0	0.0	0.0	31500	28788	0	0.0
DWwin	65%	-2963	Ton	12	1500	0.0	0	0.0	0.0	18000	15037	0	0.0
DOlive	44%	-3717	Ton	1.4	5000	0.0	2200	2.6	7500	26388	22671	0	0.0

3.9.2 Short-term crop budgets

The short-term crop budgets include 20 vegetable crops. Lucerne is also included here although it is more of a perennial crop. Table 3.22 shows the most important information with regard to gross margins of these crops. Where market cost (marketing costs) is not provided, it means that the market cost has already been subtracted from the price.

Table 3.22: Short-term crop budget information in Rand per ha (2000)

Crop	Direct costs	Market costs	Yield unit	Yield	Price / unit	Gross income	Gross margin	Water use m^3/ha	GM per m^3
ICauli	15252	2750	Each	22000	1	22000	3998	4470	0.89
ICabag	15833	2750	Each	22000	1	22000	3417	4260	0.80
IBroc	16410	2750	Each	22000	1	22000	2840	3820	0.74
ICarrot	23851	4025	Ton	70	460	32200	4324	9136	0.47
ITom	67794	11250	5kg	9000	10	90000	10956	12640	0.87
IGrenb	15271	3094	Ton	15	1650	24750	6386	8360	0.76
IGrenp	11704	2306	Ton	15	1230	18450	4440	8360	0.53
ICucm	13037	2859	Ton	24	953	22872	6976	6368	1.10
ISalad	14665	3125	Each	25000	1	25000	7210	2910	2.48
IBeetr	12931	2573	Ton	28	735	20580	5077	3760	1.35
ISpasp	21123	3919	Ton	30	1045	31350	6308	9405	0.67
IWatle	12083	0	Each	20000	2.5	50000	37917	9405	4.03
ISwetc	11334	0	Each	40000	0.85	34000	22666	9932.5	2.28
IWmze	11523	0	Each	40000	1	40000	28477	9932.5	2.87
IPump	14610	2472	Ton	35	565	19775	2693	9405	0.29
IButter	17347	2925	Ton	30	780	23400	3128	9405	0.33
ISqua	14628	2748	Ton	28	785	21980	4605	9405	0.49
IPotat	23821	4513	Bag	3800	9.5	36100	7767	13310	0.58
ISwpot	19381	3404	Ton	35	778	27230	4445	9640	0.46
IPepp	21366	3563	Ton	30	950	28500	3571	6444	0.55
ILucer.est	3954	0	Bales	320	15	4800	846	7200	0.12
ILucer.2-3	4215	0	Bales	720	15	10800	6585	7200	0.91
ILucer.4-5	3555	0	Bales	480	15	7200	3645	7200	0.51

Watermelons, sweet corn, white maize and tomatoes have the highest gross margins. However it must be borne in mind that some of the vegetable crops can be grown in rotation in the same year. It is therefore possible for a combination of vegetables to reach higher total gross margins than any individual crop. Vegetable farmers can adapt more readily to short-term water shortages by either changing their crop combinations or by reducing the areas cultivated.

Lettuce, sweet corn, white maize and watermelons have the highest individual water use efficiency. Carrots, pumpkin, sweetpotato and butternuts have some of the lowest individual water use efficiencies. Although some other short-term crops, such as strawberries, spices and wine rootstock are also grown in the Upper-Berg, the crops in Table 3.22 are regarded as sufficient to simulate a representative agricultural water demand for the purpose of this study.

3.9.3 Labour requirements

Table 3.23 show the amount of labour hours required per ha for the enterprises in the Upper-Berg River. Almost all the enterprises are highly labour intensive. Table grapes use almost double the amount of labour of any other single crop with the exception of plums and lemons. The reason is the high quality standards required for table grapes on the international markets.

Table 3.23: Labour requirements of farm enterprises (hours per ha)

Enter	Perm	Cas	Total	Enter	Perm	Cas	Total	Enter	Perm	Cas	Total
IRwine	45	633	678	ITom	178	3049	3227	DRwin	40	538	579
IWwine	45	846	891	IGrenb	88	684	772	DWwin	40	719	759
ITable	113	5349	5462	IGrenp	69	536	605	DWhea	3.5	0.2	4
IPlum	154	2649	2803	ICucm	82	684	766	DCanol	3.5	0.2	4
ISoftc	137	2572	2708	ISalad	105	578	683	DKorog	3.5	0.2	4
ICitr	137	2572	2708	IBeetr	88	588	676	DOats	3.5	0.2	4
ILem	199	2646	2844	ISpasp	88	692	780	DPast	3.5	0.2	4
IOliv	123	357	480	IWatle	84	672	756	DLup	3.5	0.2	4
IPear	98	1999	2096	ISwetc	78	356	434	DBarl	3.5	0.2	4
IPeach	154	2384	2538	IWmze	78	356	434	DLucer	3.5	0.2	4
INect	137	2443	2580	IPump	92	772	864	DPotat	102	510	612
IAppr	137	2520	2657	IButter	88	756	844	DOlive	68	196	264
IGuav	348	1886	2234	ISqua	88	732	820	Dairy	15.0	1.0	16
ICauli	113	578	691	IPotat	146	980	1126	Sheep	3.0	0.2	3
ICabag	119	578	697	ISwpot	150	549	699	Cattle	1.5	0.1	2
IBroc	107	578	685	IPepp	174	368	542	-	-	-	-
ICarrot	105	557	661	Ilucer	18	15	33	-	-	-	-

Enter = enterprise, Perm = permanent labour, Cas = casual labour

No machine can replace the human eye when it comes to quality control for the purpose of the fresh fruit market. Lemons are also highly labour intensive due to the high yields of this enterprise (up to 100 ton per ha).

3.9.4 Irrigation requirements of crops in the Upper-Berg River

It is an impossible task to calculate an accurate "average" gross water requirement for every crop in every typical farm location of the Berg River for several reasons:

- The typical farms represent unknown locations within specific regions.
- The water requirements of crops can differ substantially over short distances because of differences in soil types, drainage and aspect (northern or southern slope etc.).
- Specific climatic conditions such as wind, evapotranspiration, rainfall frequency and intensity can also explain differences in water requirements.
- Differences sometimes occur between cultivars of the same product group.

It is not the objective of this study to make an exact assessment of the irrigation requirements of farms in the specific region. Table 3.24 shows the scaling factors for crop water requirements in the irrigation regions.

Guidelines for the water requirements of crops were obtained from the Department of Agriculture and tourism of the Western Cape province. These estimates are mostly based on requirements for crops on the Bien Donne research farm located in the Berg1 region. The approach of this study is to use these requirements as the base requirement and to scale the requirements for the other regions with a scaling factor. The scaling factor was based on advice from irrigation experts in the region.

Table 3.24: **Irrigation requirement scaling factors**

Region	Gross irrigation requirement scaling factor
Berg1	1.0
Berg2	1.1
Berg3	1.15
SAP	1.1
NAP	1.15
PB	1.15
RK	1.3

The irrigation requirements of crops increase substantially in a northern direction away from the source of the river near Franschhoek (Berg1). This is caused by the rapid decline in the annual precipitation and also increases in temperature, evaporation, and evapotranspiration. In the RK region the water requirements of crops are approximately 30 percent higher than in the Berg1 area.

3.9.5 Supplemental and deficit irrigation

The lack of norms on crop yield-water relationships in South Africa is disturbing. Although some research had been done (Burger and Deist, 1981; Paget and Lategan, 1986; Scheepers *et al*, 1991; Myburgh, 1995; Myburgh, 1996; Beukes, 1999) in South Africa on crop-water relationships, most of this research was done for wine grapes. This is ironical as wine grapes can, in contrast to most tree fruit crops, also be produced under sub-optimal irrigation such as supplemental and deficit irrigation or even dryland. No South African research on crop yield-water relationships for a variety of deciduous fruit, vegetables and citrus crops could be traced in the literature. These crops are high-value exports crops for the fresh fruit markets and must be of a high quality in order to compete in the international markets. Water stress during the production season can reduce both quantity and quality sufficiently to lead to severe negative economic consequences.

For modelling purposes, the crop-water relationship of wine grapes (Burger and Deist, 1981) was adapted for the other crops. It must however be noted that the relationships calculated for the other crops for the purpose of the study have no sound scientific base. Figure 3.10 shows these relationships.

These relationships are complex and the simple relationship in Figure 3.10 was assumed for no other reason but that there are no relationships available for other crops in the area. In Figure 3.10 dryland is assumed to be the base yield and the percentage increase is shown for each additional irrigation. The crop-water relationship in Figure 3.10 shows clearly that the most dramatic increase takes place within the first three irrigations. After this a typical diminishing return in yield sets in.

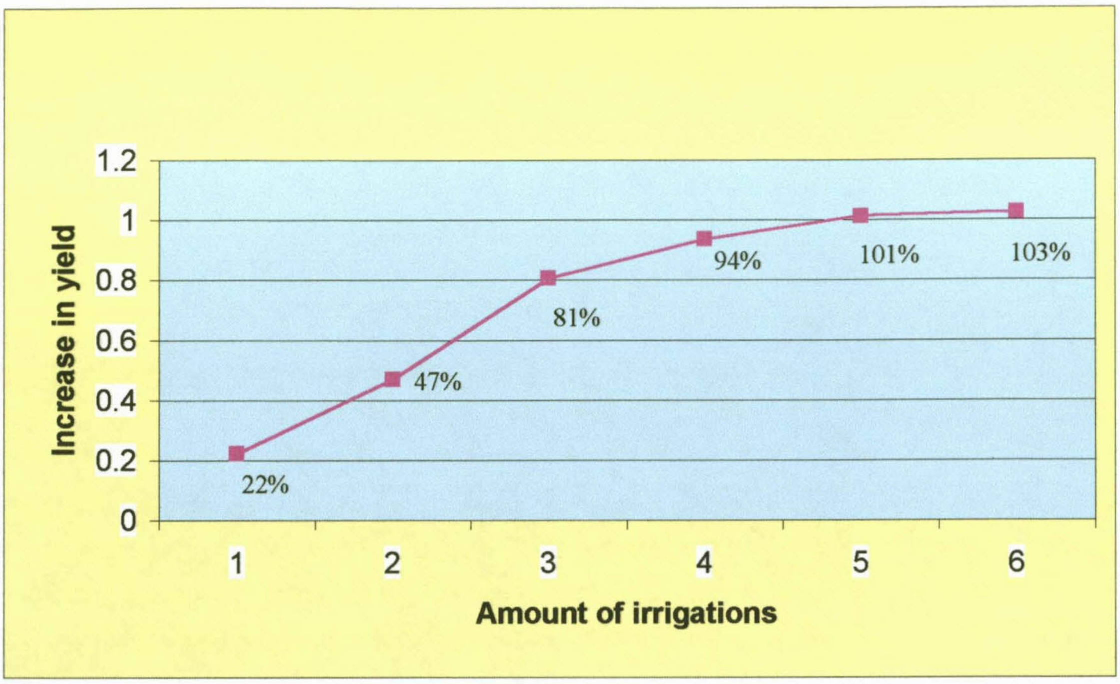

Figure 3.10: Assumed yield-water relationship

Source: Burger and Deist (1981)

It was pointed out earlier that this relation is extremely complicated because factors other than the frequency of irrigation also play important roles. The timing of irrigation is very important. During some of the biological processes, especially during bloom and fruit forming the availability of adequate water is essential to produce fruit and vegetables of good quality and in sufficient quantity. The after-harvest irrigations (March to April) are also essential to ensure that the plant can build up reserves for the next season.

3.10 Dimensions of the Berg River problem to be modelled

The description of the water supply and requirements, the irrigation regions, typical farms and the crop budgets and its input coefficients provide a background of the dimensions of the Upper-Berg River to be modelled. These dimensions can be summarised as follows:

- During the winter (the rainy season) there is ample water but in the summer (dry season) there is severe pressure on the resource due to both a high irrigation and urban demand.
- Few dam sites (and other water supply augmentations) remain for which additional storage capacity can be developed without very high cost (financial and environmental).
- During the summer months the evaporation losses are very high due to high temperatures.

- High-value export crops are being produced in the basin. This renders the basin one of the pillars of the economy of the province because of its multiplier effects. According to Eckert *et al* (1997), approximately 65% of all secondary industries are dependent on agriculture.
- Although water demand strategies have been implemented to curb the growth in urban water use, these strategies can only alleviate the problem; they cannot solve it.
- There is mounting pressure to reallocate water from agricultural use to urban use.
- Although the separation of water and land rights is advisable in the sense that it allows flexibility regarding the reallocation of water with changing demands, the system is still centrally controlled.

Internationally (see Chapter 2) water resource managers are investigating market mechanisms for solutions to water resource allocation problems. Analyses are needed to forecast effects of the use of new mechanisms in policy, such as water markets in water allocation. Such analyses need appropriate models. The rest of this thesis involves the development and use of such a model under South African conditions.

Chapter 4

MATHEMATICAL SPECIFICATION OF THE MODEL

4.1 Introduction

In this chapter a spatial equilibrium model is developed to predict the impact of a potential water market. The model includes whole farm linear programming models embedded in a spatial equilibrium framework to simulate a water demand function for agriculture and for urban water users. The model and procedures are largely based on a variety of models developed in Australia for the same purpose (see McClintock, Hilst, Lim-Applegate and Gooday 1999; Eigenraam *et al*, 1996; Eigenraam and Stoneham, 1997; Jones, James and MacAuley 1995; Hall *et al*, 1994). Positive mathematical programming (PMP) is included in the model to calibrate the regional model (see Howitt, 1995; Heckelei, 1997; Arfini and Paris, 1995; Britz, 2000). The mathematical specification of the Upper-Berg River model is also based on the theoretical overview in Chapter 2.

The following section deals with the structural outlay of the model with the various components. A section on the basic algebraic terminology follows. The fourth section presents the model mathematically and the chapter is concluded with a summary of the special characteristics of the model.

4.2 Model structure

The conceptual model structure is presented in Figure 4.1. The water supply system and water demand from the various users were discussed in Chapter 3. The combined demand of all water users may not exceed the total volume of water allocated to these users from the Theewaterskloof Dam. Water trade can theoretically take place between any of the users (e.g. x12 denotes trade between x1 and x2). However, trade is restricted by infrastructure constraints as well as transaction costs. The agricultural excess demand for water is determined by the availability of other resources and product prices. In a market regime water relocates from lower-value uses to higher-value uses and is therefore value driven.

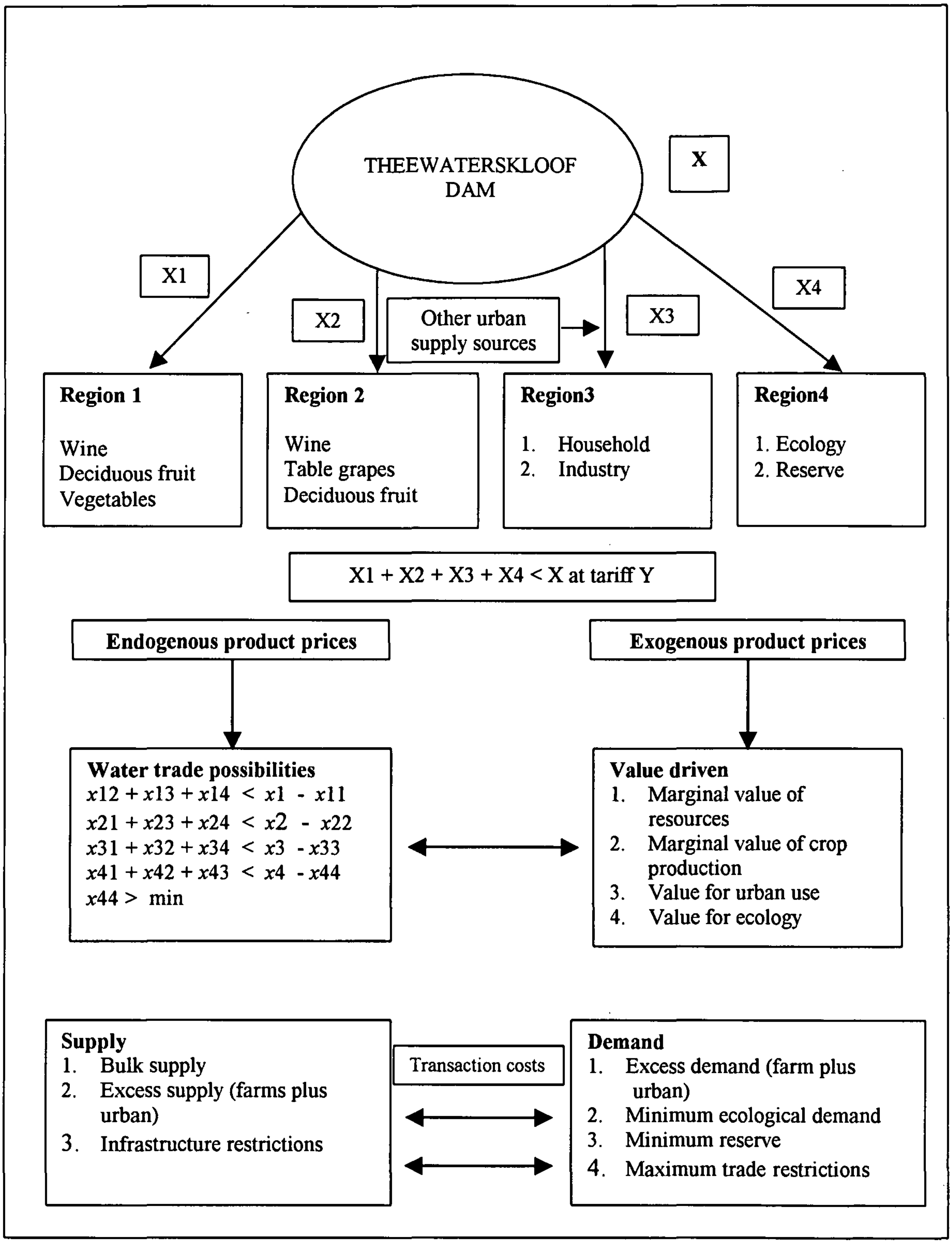

Figure 4.1: The Berg River spatial equilibrium model conceptual framework

The urban demand for water is determined by the unique value of water as a life-sustaining commodity (minimum demand to sustain life) but also by the urban sector's willingness to pay for other water uses.

South Africa is a relatively small role-player in international agricultural markets for the products produced in the Upper-Berg River. The area also produces a rather small proportion of most of these products for the South African market. The price of products produced by the agricultural sector is therefore exogenously determined.

4.3 Basic algebraic terminology

According to Brooke, Kendirck, Meeraus and Raman, (1998) the basic components of a GAMS model are:

- sets;
- data;
- variables; and
- equations.

The following sections will provide the reader with a short description of the meaning of each of these components.

4.3.1 Sets

Sets are the basic building blocks of a GAMS model, corresponding exactly to the indices in the mathematical representations of models. The members of sets are defined as elements. For example if:

I = crops then wine grapes, table grapes, citrus etc. are defined as the elements of set **I** and they are denoted as ***i***. It should be clear that the elements in set **I** could be infinite. It can sometimes be useful to have subsets for a set. For example if it proves to be necessary **C** can for instance be declared as a subset of **I** with element citrus as the only element in the subset.

Sets can also be used to relate elements to each other. For example, **H** is the set for irrigation intensity with elements (***h***) dryland, optimal, supplemental and deficit irrigation and **L** the set for landtype with elements (***l***) dryland and irrigation. It may be useful to create a set ***h*** to ***l***, meaning that optimal, supplemental and deficit irrigation relates to the irrigation land type and dryland production relates to the dryland land type.

4.3.2 Data

Data can be entered in a model through tables, lists and direct assignments, all referred to as parameters in this study. Each parameter is given a name. The data in a table can either refer to all the elements of a set or to specific data items not declared as sets or elements of sets. In the latter case the data in a table is indicated by using asterisks (*) where the asterisks denote any of the data items in the table (e.g. labour, water, yield).

To clarify the meaning of * in a parameter the following are provided as examples:
Table OHHC (***b*****,*****t*****,*****) Overhead and household costs of typical farm ***t*** in region ***b***

	Household	Overheads
Bergl.1	50 000	250 000
Bergl.2	70 000	300 000

When the parameter OHHC(***b*****,*****t*****,*****) is stated in a equation to refer to household or overheads expenses, it will be used as OHHC(***b*****,*****t*****,"Household"**) and OHHC(***b*****,*****t*****,"Overheads"**) respectively.

4.3.3 Variables

The decision variables (or endogenous variables) are also given names and must be declared as variables through a variable statement. A *z* variable must be declared to serve as the quantity to be minimised or maximised.

4.3.4 Equations

The power of algebraic modelling languages like GAMS is most apparent in the creation of the equations and inequalities that comprise the model under construction. This is because whenever a group of equations or inequalities has the same algebraic structure, all the members of the group are created simultaneously, not individually.

The spatial equilibrium model of the Upper-Berg River basin operates by maximising an objective function subject to a set of mathematical constraints. The set structure, parameters and variables are presented below, followed by the objective function and the equations (constraints) of the model. Parameters and scalars are presented in upper case and variables in lower case.

4.4 Set structure

Stating the set first and then the elements within each of the sets provides the set structure. If not in table format, the abbreviation for elements is provided in brackets. **C = set of all farm enterprises,** elements of which are donated as *c*. The enterprises are presented in Table 4.1.

Table 4.1: Elements of the set C

Description	Element	Description	Element	Description	Element
Irrigation red wine	IRwine	Irrigation tomatoes	ITom	Irrigation lucern	ILucer
Irrigation white wine	IWwine	Irrigation green beans	IGrenb	Dryland red wine	DRwin
Irrigation table grapes	ITable	Irrigation green peas	IGrenp	Dryland white wine	DWwin
Irrigation plums	IPlum	Irrigation cucumber	ICucm	Dryland wheat	DWhea
Irrigation soft citrus	ISoftc	Irrigation salad	ISalad	Dryland canola	DCanol
Irrigation citrus	ICitr	Irrigation beetroot	IBeetr	Dryland korog	DKorog
Irrigation lemons	ILem	Irrigation sweet melon	ISpasp	Dryland oats	DOats
Irrigation olives	IOliv	Irrigation water melon	IWatle	Dryland pastures	DPast
Irrigation pears	IPear	Irrigation sweetcorn	ISwetc	Dryland lupins	DLup
Irrigation peaches	IPeach	Irrigation white maize	IWmze	Dryland barley	DBarl
Irrigation nectarines	INect	Irrigation pumpkin	IPump	Dryland lucern	DLucer
Irrigation apricots	IAppr	Irrigation butternuts	IButter	Dryland potato	DPotat
Irrigation guavas	IGuav	Irrigation gemsquash	ISqua	Dryland olives	DOlive
Irrigation cauliflower	ICauli	Irrigation potato	IPotat	Dairy cattle	Dairy
Irrigation cabbage	ICabag	Irrigation sweetpotato	ISwpot	Sheep	Sheep
Irrigation broccoli	IBroc	Irrigation peppers	IPepp	Beef cattle	Cattle
Irrigation carrots	ICarrot				

I = Set of all crop enterprises, elements are donated as ***i***. **I** is a subset of **C**. Elements and subsets of **I** are listed in Table 4.2. Enterprises are grouped into subsets:

- I_v is the set of vegetable enterprises
- I_s is the set of citrus (excluding soft citrus) enterprises
- I_o is the set of all crop enterprises excluding vegetables and citrus
- I_r is the set of all the long-term crop enterprises
- I_k is the set of all the irrigation crops
- I_d is the set of all dryland crop enterprises
- I_f is the set of all feed crops or crops with crop residues which can be utilised

Table 4.2: Elements and subsets of I

Item		Subsets of I						
Description	**Element**	I_v	I_s	I_o	I_r	I_k	I_d	I_f
Irrigation red wine	IRwine			*	*	*		
Irrigation white wine	IWwine			*	*	*		
Irrigation table grapes	ITable			*	*	*		
Irrigation plums	IPlum			*	*	*		
Irrigation soft citrus	ISoftc			*	*	*		
Irrigation citrus	ICitr		*			*		
Irrigation lemons	ILem		*			*		
Irrigation olives	IOliv			*	*	*		
Irrigation pears	IPear			*	*	*		
Irrigation peaches	IPeach			*	*	*		
Irrigation nectarines	INect			*	*	*		
Irrigation appricots	IAppr			*	*	*		
Irrigation guavas	IGuav			*	*	*		
Irrigation caulliflower	ICauli	*				*		
Irrigation cabage	ICabag	*				*		
Irrigation broccoli	IBroc	*				*		
Irrigation carrots	ICarrot	*				*		
Irrigation tomatoes	ITom	*				*		
Irrigation greenbeans	IGrenb	*				*		
Irrigation greenpeas	IGrenp	*				*		
Irrigation cucumber	ICucm	*				*		
Irrigation salad	ISalad	*				*		
Irrigation beetroot	IBeetr	*				*		
Irrigation sweet melon	ISpasp	*				*		
Irrigation water melon	IWatle	*				*		
Irrigation sweetcorn	ISwetc	*				*		
Irrigation white maize	IWmze	*				*		
Irrigation pumpkin	IPump	*				*		
Irrigation butternuts	IButter	*				*		
Irrigation gemsquash	ISqua	*				*		
Irrigation potato	IPotat	*				*		
Irrigation sweetpotato	ISwpot	*				*		
Irrigation peppers	IPepp	*				*		
Irrigation lucern	ILucer			*	*	*		*
Dryland red wine	DRwin			*			*	
Dryland white wine	DWwin			*			*	
Dryland wheat	DWhea			*			*	*
Dryland canola	DCanol			*			*	*
Dryland korog	DKorog			*			*	*
Dryland oats	DOats			*			*	*
Dryland pastures	DPast			*			*	*
Dryland lupins	DLup			*			*	*
Dryland barley	DBarl			*			*	*
Dryland lucern	DLucer			*			*	*
Dryland potato	DPotat			*			*	
Dryland olives	DOlive			*			*	

A = A sub-set of *c* of all livestock enterprises, elements are denoted as ***a***.
Dairy cattle (Dairy)
Mutton and wool sheep (Sheep)
Beef (Cattle)

N = set of nutrients required by livestock, elements are denoted as ***n***.
Dry material (DM)
Total digestible nutrients (TDN)
Protein (PROT)

L = set of land types with elements denoted by ***l***. There are only two land types:
Irrigation land (Irrigat)
Dryland (Dry)

J = set of all water use types with elements donated by ***j***. There are seven irrigation regions, one urban region, the ecology and the reserve.

Irrigation water users (J_b is the irrigation user subset) :	
Upper-Berg River irrigation region one	(Berg1)
Upper-Berg River irrigation region two	(Berg2)
Upper-Berg River irrigation region three	(Berg3)
Suid-Agter-Paarl irrigation region	(SAP)
Noord-Agter-Paarl irrigation region	(NAP)
Perdeberg irrigation region	(PB)
Riebeek-Kasteel and Riebeek-Wes irrigation region	(RK)
Urban user (J_u is the urban user subset)	
The Cape Town Metropolitan Council	(URB)
Reserve and the ecology (J_e is the ecology and reserve subset)	
The whole river but especially the estuary	(Ecol)
The reserves includes the first 25 litre of water per capita per day plus a reservoir reserve determined by the DWAF	(Reser)

G = set of urban user sectors, elements of which are denoted as ***g***.

Ikapa (poor household users)	(Ihh)
All other household users	(Ohh)
Outdoor household	(Gar)
Commercial use	(Com)
Industrial use	(Ind)
Water use by the council	(Cou)
Unaccounted for water	(Uaw)

T = set of possible typical users, elements of which are denoted as ***t***. The Upper-Berg River model includes 20 typical farms, one urban (the CMC), one ecological and one reserve user. However, the maximum typical users per user type **J** are six at the moment (T >0<6).

Y = set of observed deviation years, elements of which are denoted as *y*. For the purpose of including risk using the MOTAD method, six observed years gross margins were used (Y = 1, 2, 3, 4, 5, 6).

M = set of months, elements of which are denoted by ***m*** (January to December).

W = set of other water supply sources to the urban sector, elements of which are denoted as ***w***.

Table Mountain dams	(Tabled)
Upper and lower Steenbras Dams	(Steenbr)
Wemmershoek Dam	(Wemmer)
Voëlvlei Dam	(Voelvl)
Palmiet River pump scheme	(Palmiet)
Aquafers around Cape Town	(Aquaf)

P = set of other possible water supply augmentation schemes, elements of which are denoted as ***p***.

Skuifraam Dam	(Skuifr)
Lower Hangklip	(Lowhang)
Upper-Campunula	(Campun)
Voëlvlei-Lorelei	(Vvlore)

Molenaars River	(Molen)
Lourens River	(Lour)
Cape flats aquifer	(CapeFL)
Desalination of seawater	(Desal)
Recycling	(Recy)

H = set of irrigation intensity possibilities, elements which are denoted as ***h***. There are four levels:

Optimal irrigation	(Opt)
Supplemental irrigation	(Supp)
Deficit irrigation	(Defc)
Dryland	(Dry)

For the purpose of this study, supplemental irrigation is defined as three to four irrigations per season. Deficit irrigation is defined as lower intensity irrigation over the whole season with the exception of irrigation during specific critical phases of the production season (for instance during blooming, fruit set and post harvest irrigations). However strict quality demands by the fresh produce markets preclude the possibility to do supplemental or deficit irrigation on some crops. It is for instance not possible to produce high quality table grapes, prunes and vegetables under lower intensity irrigation.

h_to_l(h,l) = a set of relating irrigation intensity to land type
Optimal, deficit and supplemental irrigation intensities relate to irrigation land ((Opt,Supp,Defc).Irrigat) and dryland relates to dryland (Dry.Dry)

Alias statements

Alias statements are a convenient way of giving another name to a previously declared set. It is useful for sets where there are interactions between the elements within the same set. The following alias statements were used.

Alias (j,jp);

Alias (t,tp);

Alias (l,lp);

Alias (h,hp);

Alias (b,bp);

4.5 Parameters

Parameters are the exogenous data supplied to the model and consist largely of the input coefficients, restriction values (right-hand side values) and scalars for the model. In the description of the parameters, the sets are not always described in the sequence that they appear in the parameter. This is done to make the description logical. It will for example not make much sense to describe ALAND_{btl} as region ***b*** typical farm ***t*** availability of landtype ***l***. Instead, availability of land type ***l*** to typical farm ***t*** in region ***b*** makes more sense. The Upper-Berg model has the following parameters:

$\mathbf{TYPD}_{jt}$	Defines the typical water users ***t*** in region ***j***
$\mathbf{ALAND}_{btl}$	Availability of land type ***l*** to typical farm ***t*** in region ***b***
$\mathbf{AREAU}_{im}$	Monthly land requirement for land type of crop ***i*** in month ***m***
$\mathbf{OH}_{bt*}$	Overhead and household expenses of typical farm ***t*** in region ***b***
$\mathbf{TYP}_{cbt}$	Defines enterprise combinations ***c*** for typical farm ***t*** in region ***b***
$\mathbf{MAXAREA}_{cbt}$	Maximum base amount of enterprise ***c*** on typical farm ***t*** in region ***b***
$\mathbf{MAXGRCT}_{bt*}$	Maximum base amount for a combination of vegetables and citrus crops of typical farm ***t*** in region ***b*** where * denotes the citrus or vegetable area
$\mathbf{CT}_{jtjpt*}$	Transaction costs of transferring water between typical water user ***t*** in region ***j*** and ***jp*** where * denotes transaction costs for permanent or temporary transfers
$\mathbf{BUDSC}_{cbt}$	Scaling of budget information for enterprise ***c*** on typical ***t*** in region ***b***
$\mathbf{CRBD}_{c*}$	Budget data coefficients * for enterprise ***c***. Where * denotes casual labour (Clab), fixed labour (Flab), water (Water), yield (Yield) and present value of gross margins (PV)
$\mathbf{DEV}_{cy}$	Deviation point ***y*** from the average gross margin for enterprise ***c***
$\mathbf{NCONT}_{fn}$	Nutrient contents nutrient ***n*** in feed crop ***f***
$\mathbf{NREQ}_{an}$	Nutrient requirement for nutrient ***n*** for animal unit ***a***
$\mathbf{WDC}_{btq}$	Water entitlement and dam capacity ***q*** of typical farm ***t*** in region ***b***
$\mathbf{ALLOCAV}_{mq}$	Monthly availability of water source ***q*** in period ***m***
$\mathbf{MIRC}_{btm}$	Water delivery capacity of typical farm ***t*** in region ***b*** in period ***m***
$\mathbf{MSCIRC}_{bm}$	Irrigation board scheme capacity for region ***b*** in period ***m***

$\mathbf{WC}_{im}$	Water requirement of crop i in period m
$\mathbf{WT}_{bt}$	Scaling factors for water requirements in region b on typical farm t
$\mathbf{IRINT}_{ih}$	Irrigation intensity possibilities h for crop i
$\mathbf{IRINTSC}_{mh}$	Scaling of irrigation requirements in period m for irrigation intensity h
$\mathbf{IRINCSC}_{ih}$	Scaling of the gross margin of crop i when using irrigation intensity h
$\mathbf{TOTWDEF}_{ih}$	Annual water requirement of crop i when applying irrigation intensity h
$\mathbf{URBVOL}_{mutg}$	Base water demand of urban use u in typical region t by user g in period m
$\mathbf{URBMIN}_{mutg}$	Minimum water demand of urban use u in typical region t by user g in period m (only applicable for human consumption)
$\mathbf{URBPR}_{mutg}$	Base price of water for urban use u in typical region t by user g in period m
$\mathbf{ECRS}_{met}$	Water requirements for the ecology and reserve use e in typical region t during period m
$\mathbf{MXURBALLO}_{ut}$	Maximum allocation for urban use u in urban use region t
$\mathbf{THEEREL}_{m}$	Maximum release capacity of the Theewaterskloof Dam in period m
$\mathbf{CTWS}_{w*}$	Other water supply sources w for the urban sector where * denotes the volume (Vol) and tariff (Wtariff) for source w
$\mathbf{CTWALT}_{p*}$	Alternative water supply sources p for the urban sector where * denotes the volume (Vol) and cost (Cost) for source w
$\mathbf{WIT}_{jt}$	Water tariff of the DWAF for raw water supply to typical region t for water user j
$\mathbf{AGGREGO}_{bt*}$	Aggregation factors for typical farm t in region b to aggregate livestock production activities to the Upper-Berg level where * denotes the aggregation factor for livestock
$\mathbf{AGGREGIR}_{bt*}$	Aggregation factors for typical farm t in region b to aggregate irrigation and dryland area to Upper-Berg level where * denotes the aggregation factor for dryland or irrigation land
$\mathbf{AGRIW}_{bt}$	Aggregation factor for typical farm t in region b to aggregate water entitlement to represent region b
$\mathbf{AGRIDAM}_{bt}$	Aggregation factor for dam capacity on typical farm t in region b
$\mathbf{ALPHA}_{utgm}$	Constant of inverse demand function for urban region u, typical urban user t for the urban use sector g in period m

$\mathrm{CONSTSUP}_{utgm}$	Constant of water supply cost function to urban region ***u*** typical urban user ***t*** use sector ***g*** in period ***m***
$\mathrm{SLOPESUP}_{gm}$	Slope of water supply cost function for urban use sector ***g*** in period ***m***
ELAST_{utg}	Defines the price elasticity of demand for urban region ***u*** typical urban user ***t*** use sector ***g***
PMPAC_{ihbt}	Constant term of marginal cost function for crop ***i*** with irrigation intensity ***h*** in region ***b*** on typical farm ***t***
PMPAA_{abt}	Constant term of marginal costs function for livestock enterprise ***a*** in region ***b*** on typical farm ***t***
PMPBC_{ihbt}	Slope of marginal costs function for crop ***i*** with irrigation intensity ***h*** in region ***b*** on typical farm ***t***
PMPBA_{abt}	Slope of marginal costs for livestock enterprise ***a*** in region ***b*** on typical farm ***t***
LOBND	Relative lower bound for flexibility constraints
UPBND	Relative upper bound for flexibility constraints
TOTCAP	Total capacity of the Theewaterskloof Dam
TRADE	Puts trade on or of
PTRFCAGRI	Fixed transaction costs for permanent trade in agriculture per transaction
TTRFCAGRI	Fixed transaction costs for temporary trade in agriculture per transaction
PTRFCURBAN	Fixed transaction costs for permanent trade from the agricultural sector to the urban sector per transaction
TTRFCURBAN	Fixed transaction costs for temporary trade from the agricultural sector to the urban sector per transaction
RISKAVC	Risk aversion coefficient
DEVCON	Deviation conversion coefficient
SUPELAS	Supply elasticity of water works

4.6 Variables

The Upper-Berg River model contains several types of variables. They are described in terms of the variables contained in the objective function, the agricultural production variables and the water-use variables.

4.6.1 Variables included in the objective function

The following combinations of variables are included in the objective function:

conssur	Consumer surplus of water use
totndi	Net disposable income aggregated over all typical farms (producer surplus)
$watinc_u$	Income from water sales by the metropolitan water works department
watwrkc	Water supply cost of the metropolitan water works department
othwatc	Other water supply costs including the DWAF tariff for bulk water supply from all urban water supply sources and the transaction cost when trade is set on
z	Total welfare (objective function value)

If watwrkc is subtracted from $watinc_u$ the balance is the producer surplus of the metropolitan water works department.

4.6.2 Agricultural production variables

The agricultural production variables are the building blocks for the construction of the typical farms in the model. They are the following:

lst_{abt}	Amount of livestock enterprise ***a*** produced in region ***b*** on typical farm ***t***
cr_{ihbt}	Area of crop ***i*** grown with irrigation intensity ***h*** on typical farm ***t*** in region ***b***
$crlttot_{br}$	Total long-term crop ***r*** area produced in region ***b***
$crvegtot_{bv}$	Total vegetable crop ***v*** area produced in region ***b***
$crdrtot_{bd}$	Total dryland crop ***d*** area produced in region ***b***
$crltt_r$	Total long-term crop ***r*** area in the Upper-Berg River
$crvegt_v$	Total vegetable crop ***v*** area in the Upper-Berg River
$crdrt_d$	Total dryland crop ***d*** area in the Upper-Berg River
rcp_{ihb}	Sum of regional production volume of crop ***i*** in region ***b***
tcp_i	Sum of total production volume of crop ***i*** for all regions
rap_{ab}	Sum of regional production volume of livestock ***a*** for region ***b***
tap_a	Sum of total production volume of livestock ***a*** for all regions
rfl_{bt}	Permanent labour use in region ***b*** of typical farm ***t***
tfl_b	Total permanent labour use in region ***b***

rcl_{bt}	Regional casual labour use in region b on typical farm t
tcl_{b}	Total casual labour use in region b
oc_{bt}	Overhead costs for typical farm t in region b
hc_{bt}	Household costs for typical farm t in region b
ndi_{bt}	Net disposable income of typical farm t in region b
ndc_{bty}	Negative deviation counters in region b for typical farm t in period y
sdev_{bt}	Estimated standard deviation in region b for typical farm t
pmpcr_{bt}	Total of the PMP parameter for region b on typical farm t : Crops
pmpliv_{bt}	Total of the PMP parameter for region b on typical farm t : Livestock

4.6.3 Water trade and water use variables

The variables in this group comprise of water supply, water trade and demand activities. Also included are the variables for calculating the urban price for water.

tfawpfr_{bt}	Permanent trade from other users to typical farm t in region b
tfawpto_{bt}	Permanent trade to other users from typical farm t in region b
raw_{b}	Annual water demand in region b
totfaw_{bt}	Total annual water demand for typical farm t in region b
tfmw_{btm}	Water demand for typical farm t in region b in period m
totaptrs_{btm}	Permanent water rights available for trade on typical farm t in region b in period m
totapmt_{bt}	Total permanent water rights of typical farm t in region b after permanent trade
tfwttrfr_{btm}	Temporary trade from other users to typical farm t in region b in period m
tfwttrto_{btm}	Temporary trade to other users from typical farm t in region b in period m
msumtrfr_{bt}	Sum of temporary trade from other users to typical farm t in region b
msumtrto_{bt}	Sum of monthly temporary trade to other users from typical farm t in region b
tfmdtr_{btm}	Water transfers from farm dam capacity on typical farm t in region b during period m
rmw_{bm}	Total water demand for region b in period m
urbdem_{utgm}	Urban demand for urban region u typical urban user t by urban water use sector g in period m
tmurbdem_{utm}	Total urban water demand for urban region u typical urban user t in period m for all urban use sectors

urbsum_{ut}	Sum of urban water demand in region u for typical urban user t
urbptrto_{ut}	Permanent trade to other users from urban region u typical urban user t
urbptrfr_{ut}	Permanent trade from other users to urban region u typical urban user t
urbttrto_{utm}	Temporary trade to other users from urban region u typical urban user t in period m
urbttrfr_{utm}	Temporary trade from other users to urban region u typical urban user t in period m
permu_{ut}	Total permanent water rights available to satisfy urban demand in region u for typical urban user t
urbttsto_{ut}	Sum of temporary trade to other users from urban region u typical urban user t
urbttsfr_{ut}	Sum of monthly temporary trade from other users to urban region u typical urban user t
vhpri_{utgm}	Price of water for urban use by typical user t for urban use sector g in period m
qwsi_{bt}	Volume of entitlement water sold to typical farm b in region t by DWAF
qwsu_{ut}	Volume of entitlement water sold to urban water utility for urban region u typical user t by DWAF
qwbi_{bt}	Volume of allocation water bought by typical farm t in region b from DWAF
qwbu_{ut}	Volume of allocation water bought from DWAF by urban water utility for urban region u typical urban user t
qwbum_{utm}	Water withdrawal from Theewaterskloof Dam for urban use in region u typical urban user t in period m
ptvw_{jtjpt}	Volume of water transferred from water use region j by typical user t to region jp by typical user t: permanent trade
ttvw_{jtjptm}	Volume of water transferred from water use region j by typical user t to region jp by typical user t: temporary trade
vwdam_{bt}	Farm dam water capacity in region b of typical farm t
winterw_{bt}	Annual total volume of winter water allocation used by typical farm b in region t
winterd_{bt}	Annual volume of winter water allocation used by typical farm b in region t to fill up farm dam
winteri_{bt}	Annual volume of winter water allocation used by typical farm b in region t for direct extraction from the river to irrigate

winterim$_{btm}$	Volume of winter water allocation used by typical farm ***b*** in region **t** in period ***m*** for irrigation
winterdm$_{btm}$	Volume of winter water allocation used by typical farm ***b*** in region **t** in period ***m*** to fill up farm dam
auwso$_{utw}$	All other urban water sources ***w*** available for urban region ***u*** typical user ***t***
ouws$_{utp}$	Alternatives water augmentation source possibilities ***p*** for urban region ***u*** typical urban user ***t***
ecolres$_{met}$	Ecological and reserve demand ***e*** in use region ***t*** in period ***m***

4.7 Objective function

The objective is to simulate the competitive market equilibrium by maximising the aggregated net disposable income (NDI) of typical farms plus the consumer valuation of water plus the producer surplus of the water works department (CMC) of supplying urban water after the bulk water supply cost of water to urban and irrigation users and the transaction cost with water trade have been subtracted.

$$\max Z = totndi + conssur + \{\sum_{utgm} vhpri_{utgm} \times urbdem_{utgm} \text{ - } watwrkc\} \text{ - } othwatc$$

Where:

The first term is the aggregated net disposable income of typical farms.

$$totndi = \sum_{bt} ndi_{\mathrm{bt}}$$

The second term is the consumer valuation of water (consumer surplus).

$$conssur = \sum_{utgm} ((ALPHA_{utgm} - vhpri_{utgm}) \times urbdem_{utgm}) \times 0.5$$

The first part of the equation calculates the area of the square (constant on the price axis multiplied by the volume on the quantity axes). The equation is then multiplied by 0.5 in order to calculate area of the triangle which represents the consumer valuation of water (the area above the supply curve).

The third term is the producer surplus of water supply where *watwrkc* is the supply cost of the water works.

$$wattwrkc = 0.5 \times \left\{ \sum_{gm} SLOPESUP_{gm} \times \left(\sum_{gm}^{ut} urbdem_{utgm} \right)^2 \right\} + \sum_{gm}^{ut} urbdem_{utgm} \times CONSTUP_{utgm}$$

The last term is other water costs and includes the water DWAF tariff for other supply dams, for alternative water sources (e.g. desalination and recycling), the tariff for Theewaterskloof Dam water and transfer costs when water trading takes place.

$$othwatc = \sum_{utw} auwso_{gm} \times CTWS_{w*} + \sum_{utp} ouws_{utp} \times CTWALT_{p*} + \sum_{utp} qwsu_{ut} \times WIT_{ut}$$

$$+ \sum_{jptput} ptvw_{gm} \times CT_{jptput*} + \sum_{jptputm} ttvw_{jptputm} \times CT_{jptput*}$$

4.8 Equations

The equations are described in two sections. The first section deals with the agricultural production equations including land use, trade and water use. The second section describes the urban demand water supply and price equations.

4.8.1 Agricultural production equations

The agricultural production equations are typical of those normally used in whole farm planning models. This section discusses these equations in more detail.

4.8.1.1 Land use and production equations

The first two equations constrain production to the total availability of land. The second equation constrains the model to the monthly availability of land. The objective of the latter is to provide for double cropping with short-term crops. The other equations aggregate the areas and volumes of crop production.

Constraint 1 aggregates the crop area for all crop types and irrigation levels in each region and soil type and should be less than or equal to the area of each soil type (dryland or irrigation) in each region.

$$\sum_{ih}^{btl} cr_{ihbt} \leq ALAND_{btl} \times AGGREGIR_{btl}$$

Constraint 2 is the availability of irrigation land to produce crop ***k*** with irrigation intensity ***h*** in region ***b*** on typical farm ***t*** and land type ***l*** in period ***m***.

$$\sum_{kh}^{btlm} cr_{khbt} \leq ALAND_{btl} \times AGGREGIR_{btl}$$

This constraint ensures that double cropping with vegetables can take place without exceeding the aggregated land availability in any period.

Constraint 3 aggregates the total regional area under long-term crops.

$$crlttot_{br} = \sum_{ht}^{br} cr_{rhbt}$$

Constraint 4 aggregates the total regional area under vegetable crops.

$$crvegtot_{bv} = \sum_{ht}^{bv} cr_{vhbt}$$

Constraint 5 aggregates the total regional area under dryland crops.

$$crdrtot_{bd} = \sum_{ht}^{bd} cr_{dhbt}$$

Constraint 6 aggregates the total area in the Upper-Berg River of long-term crops.

$$crltt_{r} = \sum_{b}^{r} crlttot_{br}$$

Constraint 7 aggregates the total area in the Upper-Berg River of vegetable crops.

$$crvegt_{v} = \sum_{b}^{v} crvegtot_{v}$$

Constraint 8 aggregates the total area in the Upper-Berg River of dryland crops.

$$crdrt_{d} = \sum_{b}^{d} crdrtot_{d}$$

Constraint 9 represents the regional production of all crops and this should be equal to the sum of the crop production on all typologies, land types and irrigation levels in each region.

$$rcp_{ihb} = \sum_{t}^{ihb} cr_{ibt} \times CRBD_{i*}$$

The asterisk denotes yield.

Constraint 10 aggregates of the regional crop production over all production regions.

$$tcp_i = \sum_{hb}^{i} rcp_{ihb}$$

Constraint 11 represents regional production of all livestock enterprises and this should be equal to the sum of livestock production over all typologies in each region.

$$rap_{ab} = \sum_{t}^{ab} lst_{abt} \times CRBD_{a*}$$

The asterisk denotes volume of production per livestock unit.

Constraint 12 aggregates the regional livestock production over all production regions.

$$tap_a = \sum_{b}^{a} rap_{ab}$$

4.8.1.2 Other resource equations

The other resource equations include equations to balance feed production with feed requirements and to calculate the permanent and casual labour requirements.

Constraint 13 represents the sum of nutrient requirements and this should be equal to or less than the sum of nutrients produced by the feed crops.

$$+\sum_{a}^{btn} lst_{abt} \times NREQ_{an} - \sum_{fh}^{btn} cr_{fhbt} \times NCONT_{fn}$$

Constraint 14 represents the regional permanent labour hour requirement and should be equal to the sum of permanent labour use by all crop and livestock activities over all typologies in a region.

$$rfl_{bt} = +\sum_{a}^{bt} lst_{abt} \times CRBD_{a*} + \sum_{ih}^{bt} cr_{ihbt} \times CRBD_{a*}$$

The asterisk denotes the fixed labour requirements per unit of production. In this model the availability of permanent labour is not considered to be a constraint. However, it is important to be able to measure the change in the amount of labour used in order to point out certain social aspects with regard to water policy decisions.

Constraint 15 represents the regional casual labour hours required and it is equal to the sum of casual labour used by all crop and livestock activities over all typologies in a region.

$$rcl_{bt} = +\sum_{a}^{bt} lst_{abt} \times CRBD_{a*} + \sum_{ih}^{bt} cr_{ihbt} \times CRBD_{a*}$$

The asterisk denotes the casual labour requirements per unit of production. The availability of casual labour is also not considered to be a constraint. However, it is also important to be able to calculate the amount of labour use for the same reason as in Constraint 14.

Constraint 16 aggregates the regional fixed labour requirement over all production regions for all crop and livestock activities.

$$tfl_{b} = \sum_{t}^{b} rfl_{bt}$$

Constraint 17 aggregates the regional casual labour requirement over all production regions, for all crop and livestock activities.

$$tcl_{b} = \sum_{t}^{b} rcl_{bt}$$

4.8.1.3 NDI calculations

The first two equations force overhead and household cost activities into the solution. This is followed by an equation that calculates the NDI for typical farms.

Constraint 18 represents total overhead cost and it is equal to the overhead cost per typical farm multiplied by the aggregation factor for the typology.

$$oc_{bt} = Oh_{bt} \bullet \times A\mathring{G}RIW_{bt}$$

The asterisk denotes overhead costs.

Constraint 19 represents total household cost and is equal to the household cost per typical farm multiplied with the aggregation factor for the typology.

$$hc_{bt} = Oh_{bt} \bullet \times AGRIW_{bt}$$

The asterisk denotes household expenses.

Constraint 20 calculates the net disposable income per typical farm in each of the irrigation regions.

$$ndi_{bt} = +\sum_{a}^{bt} lst_{abt} \times CRBD_{a*} \times BUDSC_{abt} + \sum_{ih}^{bt} cr_{ihbt} \times CRBD_{i*} \times IRINSC_{ih} \times BUDSC_{ibt}$$

The terms above calculates the total gross margin per typical farm in each region. The asterisk denotes the present value of the gross margin over a 20-year period at a 13 percent interest rate (see Chapter 5 for a discussion of the interest rate). The rate can be changed easily to accommodate changes in economic indicators. All gross margins are adapted with scaling factors to better represent the different irrigation regions. The following terms are the transaction costs.

$$-\sum_{jptp}^{bt} ptvw_{jptpbt} \times CT_{jptpbt*} - \sum_{jptp}^{bt} ttvw_{jptpbt} \times CT_{jptpbt*}$$

The asterisk in the left term denotes the transaction cost of temporary trade and the asterisks in the right-hand term the transaction cost of permanent trade. After the transaction costs the overhead costs, household expenses and the standard deviation are subtracted.

$$-OC_{bt} \times AGRIW_{bt} - HC_{bt} \times AGRIW_{bt} \text{ - } sdev_{bt} \times RISKAVC$$

The left-hand term is the aggregated overhead cost, the middle term the aggregated household cost and the right-hand term the standard deviation multiplied by the risk aversion coefficient. This is followed by a subtraction of the cost of buying water from the DWAF.

$$-WIT_{bt} \times (qwbi_{bt} + tfawpfr_{bt} + msumtrfr_{bt})$$

It is assumed that farmers also pay the tariff for temporary traded water. The value of temporary traded water rights therefore does not include the tariff for the actual delivery of the water. Finally, in the last part of the equation, the PMP parameters are added.

$$+\{\sum_{a}^{bt} 0.5(PMPBA_{abt} \times lst_{abt}^{2}) + PMPAA_{abt}\} + \{\sum_{ih}^{bt} 0.5(PMPBC_{ihbt} \times cr_{ihbt}^{2}) + PMPAC_{ihbt}\}$$

The parameters represents marginal cost functions (which are quadratic) for livestock and crop production activities. Appendix B provides a detailed description of the PMP technique.

The calculation of the NDI can be summarised as follows: The net disposable income for each typical farm in every region is equal to the sum of the gross margins for the production activities over all land types and irrigation intensities minus the cost of water minus overhead and household cost minus the negative utility from risk aversion minus the transfer cost of water trade plus the PMP terms. The PMP term is the marginal cost function for all production activities and ensures that the model calibrates to the observed base-year activities without calibration constraints.

4.8.1.4 Calibration constraints

The calibration constraints are utilised in the first step during the calculation of the PMP parameters. During this step the dual values on the calibration constraints are calculated, which are then used in the second step to construct marginal cost functions for agricultural production activities. The marginal costs are then added in the calculation of the NDI, this ensures that the model calibrates to the exact base-year solution without calibration constraints.

Constraint 21 represents the minimum area of all crop activities with the exclusion of vegetables and citrus. This constraint is a calibration constraint that only applies to calculate the PMP parameter. After the PMP parameters have been calculated the constraint is released.

$$\sum_{h}^{obtl} cr_{ohbt} \geq MAXAREA_{obt} \times AGGREGIR_{btl} \times LOBND$$

The term LOBND is used to trim the lower boundary on the production activities.

Constraint 22 represents the maximum area of all crop activities with the exclusion of vegetables and citrus. This constraint is a calibration constraint that also applies only to calculate the PMP parameter.

$$\sum_{h}^{obtl} cr_{ohbt} \leq MAXAREA_{obt} \times AGGREGIR_{btl} \times UPBND$$

The term UPBND is used to trim the upper boundary on the production activities.

Constraint 23 represents the minimum area for a combination of vegetables. The model calculates a combination of 20 different vegetable activities, which may not exceed the total area allocated to vegetables based on the observed area for each typical farm. The asterisk denotes the area allocated to vegetables.

$$\sum_{vh}^{bt} cr_{vhbt} \geq MAXGRCT_{bt*} \times AGGREGIR_{btl} \times LOBND$$

Constraint 24 represents the maximum area for a combination of vegetables. The asterisk denotes the area allocated to vegetables.

$$\sum_{vh}^{bt} cr_{vhbt} \leq MAXGRCT_{bt*} \times AGGREGIR_{btl} \times UPBND$$

The term UPBND is used to trim the upper boundary on the area allocated to vegetables.

Constraint 25 represents the minimum amount of livestock units of all livestock activities. This constraint is also a calibration constraint that only applies to calculate the PMP parameter.

$$lst_{abt} \geq MAXAREA_{abt} \times AGGREGO_{bt*} \times LOBND$$

The asterisk denotes the aggregation factor for livestock units per region. The term LOBND is used to trim the lower boundary on the production activities.

Constraint 26 represents the maximum amount of livestock units for all livestock activities.

$$\sum_{abt} lst_{abt} \leq MAXAREA_{abt} \times AGGREGO_{bt*} \times UPBND$$

The asterisk denotes the aggregation factor for livestock units per region. The term UPBND is used to trim the upper boundary on the livestock activities.

4.8.1.5 Risk equations

Risk is included in the model by using standard deviations and a risk aversion parameter. The first equation calculates the deviation from the average gross margin over six years and the second the sample standard deviation.

Constraint 27 calculates the deviation from the gross margin trend over a period of six years.

$$+\{\sum_{a}^{bty} lst_{abt} \times CRBD_{a*} \times BUDSC_{abt} \times DEV_{ay} - lst_{abt} \times CRBD_{a*} \times BUDSC_{abt}\}$$

$$+\{\sum_{ih}^{bty} cr_{ihbt} \times CRBD_{i*} \times BUDSC_{ibt} \times DEV_{iy} - cr_{ihbt} \times CRBD_{i*} \times BUDSC_{ibt}\} - ndc_{bty} \geq 0$$

Constraint 28 calculates the sample standard deviation for each typical farm in the irrigation regions. The term CARD returns the number of elements in the set **y** (in the case of the Upper-Berg River model this is the six observed deviations).

$$SDEV_{bt} = \sqrt{\sum_{y}((ndc_{bty} + 0.001)^2 \div (CARD_y - 1))}$$

The standard deviation multiplied by the risk aversion coefficient is subtracted from the net disposable income (NDI).

4.8.2 Water use and balancing equations

The constraint equations in this group are designed to first calculate the water demand for each user and then to equate the demand with supply through the water entitlement, water trade and other water sources.

Constraint 29 denotes the water requirement of irrigation crops per typical farm in each of the irrigation regions and cannot exceed the total availability of water for irrigation.

$$\sum_{kh}^{bt} cr_{khbt} \times TOTWDEF_{kh} \times WT_{bt} - totfaw_{bt} = 0$$

Constraint 30 represents the total annual amount of water available for irrigation acquired through allocation water (winter and summer), permanent and temporary trade (if trade is permitted) and available dam capacity. It is assumed that the dam is filled up with a certain percentage of capacity through natural run-off.

$$totfaw_{bt} \leq qwbi_{bt} + tfawpfr_{bt} - tfawpto_{bt} + msumtrfr_{bt} - msumtrto_{bt} + vwdam_{bt} + winteri_{bt}$$

Constraint 31 sums the volume of water acquired by a typical farm through permanent trade of water rights from other users.

$$\sum_{jptp}^{bt} ptvw_{jptpbt} = tfawpfr_{bt}$$

Constraint 32 sums the volume of water rights permanently traded by a typical farm to other users.

$$\sum_{jptp}^{bt} ptvw_{btjptp} = tfawpto_{bt}$$

Constraint 33 represents the maximum volume of permanently traded water rights to other users from the agricultural sector. The volume may not exceed the quantity of water entitled to the agricultural sector. The term TRADE switches trade on or off by changing the value of TRADE to 0 or 1.

$$\sum_{jptp}^{bt} ptvw_{btjptp} \leq qwbi_{bt} \times TRADE$$

Constraint 34 represents the maximum amount of permanent trade from other users to the urban water use sector and it cannot exceed the quantity of water demanded by the urban sector. This constraint specifies that speculation is not permitted.

$$\sum_{jptp}^{ut} ptvw_{jptput} \leq urbsum_{ut} \times TRADE$$

Constraint 35 denotes that the maximum amount of permanent trade from the urban water use sector to other water users cannot exceed the quantity of water entitlement of the urban sector.

$$\sum_{jptp}^{ut} ptvw_{utjptp} \leq qwbu_{ut} \times TRADE$$

Constraint 36 sums the annual regional irrigation water use.

$$raw_b = \sum_t totfaw_{bt}$$

Constraint 37 represents the monthly water demand per typical farm for each region. It is the sum of the irrigation crop requirements multiplied by the water requirement-scaling factor for each region multiplied by the irrigation intensity-scaling factor.

$$\sum_{khbt}^{m} cr_{khbt} \times WC_{kh} \times WT_{bt} \times IRINTSC_{mh} - tfmw_{btm} = 0$$

Constraint 38 sums the monthly regional irrigation water demand.

$$rmw_{bm} = \sum_t tfmw_{btm}$$

Constraint 39 represents typical farm irrigation water demand and must be less or equal to the irrigation system delivery capacity.

$$tfmw_{btm} \leq \sum_t MIRC_{btm} \times AGGREGO_{bt*}$$

The asterisk is the aggregation factor for irrigation system delivery capacity.

Constraint 40 sums the monthly water demand of typical farms located on an irrigation board pump scheme and subtracts the water in farm dams. This may not exceed the pump capacity of the scheme in any month.

$$\sum_t^{bm} TFMW_{btm}. - \sum_t^{bm} TFMDTR_{btm} \leq MSCIRC_{bm}$$

Constraint 41 balances monthly water demand with total annual water demand.

$$TOTFAW_{bt} = \sum_m^{bt} TFMW_{btm}.$$

Constraint 42 sums the monthly volume of water acquired by a typical farm through temporary trade from other users.

$$\sum_{jptp}^{btm} ttvw_{jptpbtm} = tfwttrfr_{btm}$$

Constraint 43 sums the monthly volume of water temporarily traded by a typical farm to other users.

$$\sum_{jptp}^{btm} ttvw_{btjptpm} = tfwttrto_{btm}$$

Constraint 44 sums the total amount of water acquired through temporary trade by a typical farm from other users.

$$\sum_{m}^{bt} tfwttrfr_{btm} = msumtrfr_{bt}$$

Constraint 45 sums the amount of water temporarily traded by a typical farm to other users.

$$\sum_{m}^{bt} tfwttrto_{btm} = msumtrto_{bt}$$

Constraint 46 balances monthly irrigation demand per typical farm with the availability from temporary trade, the farm dam, winter allocations and from the total amount of permanent water rights available.

$$\begin{aligned} tfmw_{btm} &\leq (tfwttrfr_{btm} \times ALLOCAV_{m*}) + (tfmdtr_{btm} \times ALLOCAV_{m*}) \\ &+ (totaptrs_{btm} \times ALLOCAV_{m*}) + (w\,\mathrm{int}\,erim_{btm} \times ALLOCAV_{m*}) \end{aligned}$$

$ALLOCAV_{m*}$ is a parameter indicating to the model at which time of the year a source is available. For example, summer water (Theewaterskloof Dam water) can only be pumped in the summer, the dam water throughout the year and winter water only in the winter. The value of $ALLOCAV_{m*}$ is either 0 or 1.

Constraint 47 represents the sum of monthly water use from permanent water entitlements and must be equal to the available permanent water entitlements (acquired through permanent trade and from initial entitlement).

$$\sum_{m}^{bt} totaptrs_{btm} = totapmt_{bt}$$

Constraint 48 represents the total volume of permanent water rights available to a typical farm and it is the sum of the initial entitlement plus water rights acquired through permanent trade minus water rights sold permanently to other water users.

$$totapmt_{bt} = qwbi_{bt} + tfawpfr_{bt} + tfawpto_{bt}$$

Constraint 49 represents the maximum amount of temporary trade to other users from the agricultural water-use sector. This cannot exceed initial quantity of water entitlement minus the water permanently traded to other users plus the amount acquired through permanent trade.

$$\sum_{jptpm}^{bt} ttvw_{btjptpm} \leq (qwbi_{bt} + tfawpfr_{bt} - tfawpto_{bt}).TRADE$$

Constraint 50 balances the monthly withdrawal of water from the farm dam per typical farm with the total annual withdrawal.

$$\sum_{m}^{bt} tfmdtr_{btm} = vwdam_{bt}$$

Constraint 51 balances the total withdrawal of water from the farm dam per typical farm with the total farm dam capacity. The maximum volume of water in the dam is the capacity filled up with natural in-flow plus the balance of the capacity filled up with winter water.

$$vwdam_{bt} \leq DAMAV_{bt*} \times AGRIDAM_{bt} + w\mathrm{int}\,erd_{bt}$$

The asterisk denotes the farm dam capacity filled up with natural run-off.

Constraint 52 ensures that the volume of initial entitlement water withdrawal by typical farms is less than or equal to the initial aggregated entitlement.

$$qwbi_{bt} \leq WDC_{bt*} \times AGRIW_{bt}$$

The asterisk denotes the initial aggregated summer entitlement.

Constraint 53 represents the maximum amount of water that can be pumped in the winter to fill the farm dams. This cannot exceed the capacity of the dam available for winter water.

$$w\mathrm{int}\,erd_{bt} \leq DAMAV_{bt*} \times AGRIDAM_{bt}$$

The asterisk denotes the capacity of the dam to store winter water.

Constraint 54 denotes that the sum of the monthly winter water withdrawal from the river to fill up the farm dam may not exceed the total annual withdrawal for this purpose.

$$\sum_{m}^{bt} w\text{int}\,erdm_{btm} = w\text{int}\,erd_{bt}$$

Constraint 55 denotes that the sum of the monthly winter water withdrawal from the river to irrigate may not exceed the total annual withdrawal for this purpose.

$$\sum_{m}^{bt} w\text{int}\,erim_{btm} = w\text{int}\,eri_{bt}$$

Constraint 56 denotes that the total winter withdrawal to fill the farm dam plus the volume of winter water extracted for irrigation purposes may not exceed the total winter water allocation.

$$w\text{int}\,erd_{bt} + w\text{int}\,eri_{bt} \leq w\text{int}\,erw_{bt}$$

Constraint 57 denotes that the total winter withdrawal to fill the farm dam plus the volume of winter water extracted for irrigation purposes may not exceed the total winter water allocation.

$$w\text{int}\,erw_{bt} \leq WDC_{bt*} \times AGRIW_{bt}$$

The asterisk denotes the total winter allocation per typical farm. At the moment only the Riebeek-Kasteel region has an official winter water entitlement. The riparian users are allowed to pump any amount of winter water. For the purpose of this study the on-farm pump capacity was regarded as the maximum volume that they can pump.

Constraint 58 denotes that the maximum amount of temporary trade to other users from the urban water use sector cannot exceed initial quantity of water entitlement minus the water permanently traded to other users plus the amount acquired through permanent trade.

$$\sum_{jptpm}^{ut} ttvw_{utjptpm} \leq (qwbu_{ut} + urbptrfr_{ut} - urbptrto_{ut}) \times TRADE$$

Constraint 59 sums the volume of water acquired by the urban sector through permanent trade of water rights from other users.

$$\sum_{jptp}^{ut} ptvw_{jptput} = urbptrfr_{ut}$$

Constraint 60 sums the volume of water rights permanently sold by the urban sector to other users.

$$\sum_{jptp}^{ut} ptvw_{utjptp} = urbptrto_{ut}$$

Constraint 61 sums the monthly volume of water acquired by the urban sector through temporary trade from other users.

$$\sum_{jptp}^{utm} ttvw_{jptputm} = urbttrfr_{utm}$$

Constraint 62 sums the monthly volume of water temporarily traded by the urban sector to other users.

$$\sum_{jptp}^{utm} ttvw_{utjptpm} = urbttrto_{utm}$$

Constraint 63 sums the total amount of water acquired through temporary trade by the urban sector from other users.

$$\sum_{m}^{ut} urbttrfr_{utm} = urbttsfr_{ut}$$

Constraint 64 sums the amount of water temporarily traded by the urban sector to other

$$\sum_{m}^{ut} urbttrto_{utm} = urbttsto_{ut}$$

users.

Constraint 65 represents the total permanent water rights available to a typical farm. It is the sum of the initial entitlement plus water rights acquired through permanent trade minus water rights sold permanently to other water users.

$$permu_{ut} = qwbu_{ut} - urbptrto_{ut} + urbptrfr_{ut}$$

Constraint 66 represents the monthly urban demand per urban user sector. This is the base volume of water consumption multiplied by a factor. The factor is one plus the price paid per urban use sector minus the urban sectors base price divided by the urban base price multiplied by the demand elasticity for water.

$$urbdem_{utgm} = urbvol_{mutg} \times (1 + (vhpri_{utgm} - urbpr_{mutg})) \div urbpr_{mutg} \times elast_{utg}))$$

It is assumed that in a free market the price determined by the water supply utility for water will be closely correlated to what they must pay to acquire water-use rights. The volume of water demanded by each of the urban-use sectors will therefore fluctuate with price changes.

Constraint 67 sums the monthly volume of water demanded by all urban water-use sectors.

$$\sum_{g}^{utm} urbdem_{utgm} = tmurbdem_{utm}$$

Constraint 68 sums the total volume of water demanded annually by all urban water-use sectors.

$$\sum_{m}^{ut} tmurbdem_{utm} = urbsum_{ut}$$

Constraint 69 balances the sum of the monthly urban demand for all urban water-use sectors with the total annual volume of water available for urban use. The latter is the urban water entitlement minus the volume of water temporarily and permanently traded to other users, plus the volume acquired through temporary and permanent trade from other users, plus the sum of the volume of possible alternative water sources, plus the sum of all other water sources (dams and aquifers) available to the urban sector.

$$\sum_{m}^{ut} tmurbdem_{utm} = qwbu_{ut} - urbttsto_{ut} + urbttsfr_{ut} - urbptrto_{ut} + urbptrfr_{ut} + \sum_{p}^{ut} ouws_{utp} + \sum_{p}^{ut} auws_{utw}$$

Constraint 70 ensures that the volume of initial entitlement water withdrawal by the urban sector is less than or equal to the initial entitlement.

$qwbu_{ut} \leq MXURBALLO_{ut}$.

Constraint 71 ensures that the volume of initial entitlement water supplied by the DWAF to typical farms equals the actual amount bought by them.

$$+qwbi_{bt} - qwsi_{bt} = 0$$

Although this equation is not a necessity if the model works correctly, it is a useful equation to debug the model.

Constraint 72 ensures that the volume of initial entitlement water supplied by the DWAF to the urban sector equals the actual amount bought by them.

$$+qwbu_{bt} - qwsu_{bt} = 0$$

This equation is also only used to identify the problem areas if they exist.

Constraint 73 balances the monthly water withdrawal from Theewaterskloof Dam by the urban sector with the total withdrawal after permanent trade (the real withdrawal after trade).

$$\sum_{m}^{ut} qwbum_{utm} = qwbu_{ut} - urbptrto_{ut} + urbptrfr_{ut}$$

Constraint 74 denotes that total water withdrawal from Theewaterskloof Dam by all users cannot exceed the total capacity of the dam.

$$\sum_{bt} qwbi_{bt} + \sum_{ut} qwbu_{ut} + \sum_{met} ecolres_{met} \leq TOTCAP$$

Constraint 75 denotes that total water withdrawal from Theewaterskloof Dam by all users cannot exceed the release capacity of the dam.

$$\sum_{bt}^{m} tfmw_{btm} + \sum_{ut}^{m} qwbum_{utm} + \sum_{et}^{m} ecolres_{met} \leq THEEREL_{m}$$

Constraint 76 denotes that the maximum volume of water available from other urban water supply sources cannot exceed the allocation from these sources.

$$+auwso_{utw} = CTWS_{w*}$$

The asterisk denotes the volumetric allocation from other sources.

Constraint 77 denotes that the maximum volume of water, which can potentially be extracted from possible water augmentation schemes, cannot exceed the design specification from these sources.

$$+ouws_{utp} \leq CTWALT_{p*}$$

The asterisk denotes the volumetric design capacity from these sources.

Constraint 78 balances the monthly water required by the ecology and the reserve with the volume of water allocated for this purpose.

$$\sum_{mt}^{e} ecolres_{met} = \sum_{mt}^{e} ECRS_{met}$$

4.9 Conclusion

This chapter discussed the design of the spatial equilibrium model to simulate a potential water market in the Berg River. The agricultural part of the model is to a large extent based on work done in Australia. The Australian models did however not include an urban water demand sector. The Upper-Berg River model is also unique in the sense that the model employs the PMP technique to calibrate the model. Also, the model disaggregates the urban demand sector into seven use categories. The calibration of the model with and without the PMP technique is described in Chapter 5.

Chapter 5

BASE ANALYSIS, CALIBRATION AND VALIDATION

5.1 Introduction

According to Howitt (1995) policy programming models should be calibrated to present a base year. Policy analysis based on normative models that show a wide divergence between base period model outcomes and actual production patterns is generally unacceptable. However, models that are tightly constrained can produce only that subset of normative results that the constraints can dictate. The policy conclusions are thus bounded by a set of constraints that are expedient for the base year, but often inappropriate under policy changes. This problem is exacerbated when the model is constructed on a regional basis with very few empirical constraints, but with a wide diversity of crop production. Howitt (1995) pointed out that although calibration of models to observed outcomes is an integral part of the construction of physical models, it is rarely formally analysed for optimisation models in agricultural economics.

The base model attempts to replicate the current agricultural system in the Upper-Berg River as well as water supply and demand for the urban sector. This includes current areas under production, water use and water delivery charges, technologies, policies and resource levels. It is assumed that there is no water trade between regions. This is however not quite the true situation, since there has been some permanent and temporary trading of water entitlements between farmers in the past without a formal water market structure.

Hazell and Norton (1986) suggested six tests to validate a sectoral model. They are:

- capacity test for over constrained models;
- a marginal cost test to ensure that marginal costs of production, including the implicit opportunity costs of fixed inputs, are equal to the output price;
- comparison of the dual values of land with actual land rental values;
- comparisons of input use;

- production levels;
- and product price tests.

In Chapter 2, it was pointed out that in contrast, the positive mathematical programming (PMP) approach aims to achieve exact calibration in area utilisation, production and price (Howitt, 1995). In this chapter the PMP technique is employed to calibrate the Upper-Berg River model to represent the observed land and water use for the 2000 base-year situations. In the first analysis the model runs without PMP on agricultural production activities but with calibration constraints to resemble the present agricultural production situation. The results are compared with observed land and water use. In the second analysis the model runs without PMP and without calibration constraints (optimal solution without PMP). In the final analysis the model runs with PMP and without calibration constraints and the results are compared to the model with calibration constraints but without PMP as well as with the optimal solution without PMP.

The PMP parameters for water supply to the urban sector are included in all the analysis. This is partially for illustrative purposes. In the optimal solution without PMP parameters for the agricultural sector, major differences between the model with PMP and without PMP with the exception of the urban water demand and supply will be scrutinised. This is also a test to determine whether PMP as constructed in this thesis achieves its goals.

5.2 Base model description

The methodology employed and the model description is discussed in detail in Chapter 2 and 4. The model is a non-linear spatial equilibrium model designed to represent the main irrigation areas and river pump systems as well as the urban water demand sector in the Upper-Berg River. This is done by maximising the total consumer valuation of water and the producer surplus of irrigators minus the cost of supplying water. Each irrigation region is modelled using non-linear programming. The regional submodels (with embedded typical farm models) are linked by a model of the river system and a model of water supply and demand. Water trading, transaction costs, growth in urban demand, and changes in water use are all taken into account.

5.2.1 Capitalisation rate

All prices in the model are for a discounted stream of cash inflows and outflows over a twenty-year period. This was necessary in order to cater for the static nature of the model and to capture the cash flow of long-term crops. Van Schalkwyk (1995) pointed out that from a conceptual point of view the capitalisation rate should reflect the cost of capital and also stated that adjustments are necessary to reflect differences in the risk associated with alternative investments. Furthermore the rate should reflect the value that farmers attach to farming as a way of life. For this study base prices are 1999 prices discounted with an interest rate of 13 percent (based on the median Commercial Bank 12 month fixed deposit rate of 10.75 percent minus a 6 percent expected inflation rate plus 6 percent to provide for risk plus 2.25 to provide for farming as a way of live). Since 1994 the liberalisation of trade process accelerated which is causing product prices to fluctuate more than in the past. A relatively high-risk rate was therefore assumed. The results of the model are compounded again and the result divided by 20 in order to reflect an average value.

5.2.2 Calibration analysis

For simplicity the calibration analysis is referred to as:

- BASE: Base analysis with calibration constraints but without PMP
- BASOPT: Optimal analysis without calibration constraints and without PMP
- PMPOPT: Optimal analysis without calibration constraints but with PMP

5.3 Model calibration to observed water demand and agricultural production levels

The analysis is discussed in terms of the objective function values, land use, net disposable income, labour, agricultural water demand, urban water demand, water supply and demand balance to all the user sectors, and finally the values attached to water.

5.3.1 Objective function parameters

Table 5.1 shows the values for the various components of the objective function. For the purpose of illustrating the PMP approach the value of the PMP parameters are subtracted from the objective function to show that the value of the objective function after subtraction of the PMP parameters (PMPOPT) is exactly the same as the objective function value without PMP (BASE). Therefore, by using the dual values of the calibration constraints to construct marginal cost functions for each of the production activities as well as a marginal cost function for urban water supply, it is possible to calibrate the PMP model to the exact values of the model with calibration constraints.

Table 5.1: Objective function parameters

Objective function parameters (Million)	BASE (Rand)	BASEOPT (Rand)	PMPOPT (Rand)
Objective function	7822	10040	12176
Consumer surplus	5098	5098	5097
Income from water sales by CMC	2320	2320	2320
Total utility from farming including risk	611	2829	611
Cost of water works	-7312	-7312	-4893
Other water supply costs*	-206	-206	-206
PMP parameter value	0	0	-4354
Total	**7822**	**10040**	**7822**

**Other water supply costs = transaction, other and potential water sources costs*

Without the PMP approach there is a substantial difference between the base analysis (BASE) and the optimal solution (BASEOPT). Overspecialisation takes place with regard to agricultural production when PMP is excluded. The reason is the lack of information with regard to producer behaviour. The number of binding constraints in the optimal solution is less than the number of non-zero activities observed in the base solution (Arfini and Paris, 1995; Howitt, 1995). Even with fairly accurate information of the agricultural water-use sector (through the survey and the construction of typical farms) it is not possible to accurately construct producer behaviour in the model. With the PMP approach the dual values of the observed production and water use levels are used to generate marginal cost functions of production to calibrate exactly to the base year.

This result presented in Table 5.1 therefore proves that the PMP methodology as discussed in Chapter 2 and Appendix B has been formulated correctly in the model. It must be clearly understood that with any regional trade model, the relative changes in the objective function value is more important than the value itself. This is especially true with regard to the PMP methodology as the dual values on the constraints are captured in the objective function.

5.3.2 Land use, land values and crop combinations

Table 5.2 shows a substantial deviation between the optimal solution without calibration constraints (BASEOPT) and the model with calibration constraints (BASE). This confirms the argument of Paris and Howitt (1998) regarding overspecialisation in most regional models due to incomplete information about the real world situation. They described situations like this as "ill-posed" problems when the number of unknown parameters is larger than the number of observations.

As has been indicated in Chapter 2, a serious problem is created by such large deviations between the two models in the agricultural production structure, namely that of capital expenditure and changing overhead costs. The PMP structure allows the model to react more smoothly to policy and other changes and therefore to represent a much more reliable picture of the resultant real effect on changes in the market.

Table 5.2: Land use (2000)

Base analysis	BASE	BASEOPT	PMPOPT
Long term crops: optimum irrigation (ha)	8106	11464	8107
Long term crops: deficit irrigation (ha)	763	0	763
Long term crops: supplemental irrigation (ha)	3234	1907	3234
Total long-term crop area (ha)	12103	13372	12104
Vegetable crops: optimum irrigation (ha)	1432	0	1432
Total area irrigated (ha)	13535	13372	13536
Dryland area (ha)	13860	32385	13861
Average marginal value of irrigation land (R)	58016	19848	15130
Average marginal value of dryland (R)	11837	59306	18229

The marginal land values calculated by the model provide an excellent example of the advantages of PMP. In the base model (BASE) without PMP the land values are probably a fair reflection of the real situation. The dryland value is relatively high because it is possible to cultivate dryland olives and dryland wine grapes on most of the typical farms. The only restriction on the cultivation of dryland crops is the area of dryland available. The model does not consider other restrictions facing dryland wine farmers (e.g. a surplus of low quality wine). Irrigation is constrained by several other restrictions imposed on the farmer (e.g. availability of water, on-farm as well as scheme pumping capacity). Also, the PMP parameters (marginal costs) are reflected in the NDI calculations (see Chapter 4). As soon as the calibration constraints are released the model uses all the available dryland in the Upper-Berg River to produce dryland wine (see Table 5.5) to maximise profit, and the value of dryland increases substantially. However, the opposite happens with the value of irrigation land because in the optimal solution irrigation farmers are now restricted by other restrictions, which are (as pointed out) more limiting than the availability of land). When the same analysis is conducted with the PMP technique, the model reacts smoother because the marginal cost of production (as reflected by the dual values on the calibration constraints) is reflected in the objective function.

The intuition of the PMP technique is that as the calibration constraints will necessarily be binding, the marginal cost of producing the amount of a product inflicted by the calibration constraint will be the sum of the dual variable on the calibration constraint plus the cost of producing the product. The first model (BASE) therefore reveals the economic marginal cost incurred by the decision maker, which, up to this point, is hidden - and unidentified - but implicit in the realised levels of production.

Also in the BASEOPT model, the primal objective represents the total revenue minus total variable cost. In the second stage (PMPOPT) the objective function includes the total limiting input costs (dual values) and the objective function becomes total revenue minus total variable cost minus total limiting input costs. By minimising the limited input costs (dual values) in the objective function, the model calibrates to the exact primal solution. In a certain way this can be regarded as a similar approach to the primal-dual formulation of Batterham and MacAulay (1994).

Table 5.3 presents the base model irrigation crop combinations. It was pointed out in Chapter 3 that no accurate present-day secondary data are available about land use for all of the crops produced in the Upper-Berg River. This was part of the motive for doing a representative survey. The areas indicated in the (BASE), were calculated from the farm survey. The area indicated under "Secondary" was calculated from farm survey results and cross-checked with secondary data from the Deciduous Fruit Producers Trust (2000) as well as information obtained from the SA Wine Industry Information & Systems (2000).

In the case of red wine and table grapes the deviation is only 5 percent. The white wine area deviates by 11 percent and the plum area by 17 percent. It must be pointed out that aggregation errors are included in the deviations. In Chapter 3 it was pointed out that red wine, white wine, table grapes and plums represent approximately 80 percent of the total irrigated area. The deviation is quite substantial for the other crops such as olives, apricots and nectarines and the crops included in "other". There can be two reasons for this.

It is firstly possible that the secondary data is inaccurate, as most of these calculations were based on rough estimates or on tree survey data. It is also possible, secondly that when the area under a certain crop is relatively small relative to the total irrigated area, a large deviation can be explained by sampling errors. For example, with olives being a rather specialised product, only a few big farmers in the Berg River produce the total area under olives and this may cause the aggregation to estimate the total area for the Upper Berg River to be deceiving.

Table 5.3: Irrigated land use (2000)

Irrigation crops	**BASE (ha)**	**BASEOPT (ha)**	**PMPOPT (ha)**	**Secondary (ha)**	**Deviation* %**
IRwine	3034	11324	3034	2898	-5%
IWwine	3864	0	3864	4347	11%
ITable	2837	642	2837	2982	5%
IPlum	567	3	567	485	-17%
ISoftc	518	0	518	568	9%
ICitr	194	0	194	231	16%
IOliv	368	442	368	267	-38%
IPear	296	0	295	297	1%
IPeach	147	0	147	155	5%
INect	147	0	147	175	16%
IAppr	12	0	12	98	88%
IGuav	71	0	71	62	-15%
Other#	1480	850	1480	529	-180%
Total	**13535**	**13261**	**13535**	**13094**	**-3%**

**** Deviation between PMPOPT and the survey results***

 # Other includes crops such as vegetables and pastures. Survey data does not consider double cropping.

The deviation of "other" crops can largely also be explained by the fact that "other" also includes vegetables. Although the survey data only recorded 339 ha under vegetables for the whole Upper-Berg River region, double cropping makes it possible to irrigate more than four times this area (see Table 5.4). In the secondary statistics the land allocated to vegetable production is used and not the real production area during a year period. It was decided to accept the farm survey areas for the purpose of this study. The survey results are the most recent, and probably the most accurate, estimate of the irrigated areas in the Upper-Berg River. Furthermore, the deviation from secondary sources is, with the exception of a few crops within reasonable bounds to reach the objectives. Also, the crops for which there is considerable deviation only represents a relative small area (e.g. apricots and olives).

Table 5.4 points out that double cropping with vegetables can be highly profitable. Some of these vegetable crops can be grown in seasons other than the "high" water demand season (October-March). This makes vegetables an attractive option when water scarcity forces the market or administrative mechanisms to reallocate water. The majority of the vegetables produced in the BASE as well as PMPOPT are grown in the winter. The price of winter vegetables is also normally higher than that of summer vegetables.

Table 5.4: Vegetable crops under irrigation (2000)

Crop	BASE (ha)	BASEOPT (ha)	PMPOPT (ha)
ICauli	254.3	0.0	254.3
ICabaW	254.3	0.0	254.3
ICarrW	31.3	0.0	31.3
ILettuS	223.0	0.0	223.0
ILettuW	223.0	0.0	223.0
IBeetrW	223.0	0.0	223.0
ISwpot	223.0	0.0	223.0
Total	**1431.8**	**0.0**	**1431.9**

Although dryland production was not considered to be important for the purpose of this study, it is an important component of farming activities, especially in the lower reaches of the Upper-Berg River. The most important dryland crops are wheat, lucern, oats and other pastures. The profitability of the dryland crops is supplemented by livestock farming, which was also included in the model but which will not be discussed here. The livestock mainly graze on wheat stubble and other harvest rests, as well as on dryland pastures such as lucern (see Table 5.5).

The cost price squeeze and increased competition with regard to quality caused dryland wine farming to become less important in recent years. A large proportion of wine grapes are irrigated with supplemental irrigation or deficit irrigation. For the purpose of this study, deficit irrigation is not defined as a practice only followed during water restrictions. Deficit irrigation can also be implemented to produce lower yielding crops but with a lower irrigation intensity. Supplemental irrigation is mostly used on vineyards (three to four irrigations per season), on the other hand, deficit irrigation uses less water over the whole cropping season (80 percent of the optimum during summer).

Table 5.5: Total area cultivated with dryland crops (2000)

Total area under dryland crops	BASE (ha)	BASEOPT (ha)	PMPOPT (ha)
DRwin	397.9	32385.4	397.9
DWwin	474.0	0.0	474.1
DWhea	7808.1	0.0	7808.9
DCanol	420.9	0.0	421.0
DKorog	11.0	0.0	11.0
DOats	1168.8	0.0	1168.9
DPast	1263.8	0.0	1263.7
DLup	104.3	0.0	104.3
DBarl	18.3	0.0	18.3
DLucer	2070.6	0.0	2070.6
DPotat	32.7	0.0	32.7
DOlive	90.0	0.0	90.0
Total	**13860.5**	**32385.4**	**13861.4**

5.3.3 Net disposable income

Tables 5.6 and 5.7 show the net disposable income (NDI) per m^3 for typical farms and irrigation regions respectively.

Table 5.6: Net disposable income per aggregated typical farm (2000)

Typical farm	BASE (R per m^3)	BASEOPT (R per m^3)	PMPOPT (R per m^3)
Berg1.1	4.2	10.0	4.2
Berg1.2	2.9	11.3	2.9
Berg1.3	1.1	6.4	1.1
Berg1.4	5.3	21.0	5.3
Berg1.5	12.9	35.8	12.9
Berg1.6	9.8	76.2	9.8
Berg2.1	7.8	28.6	7.8
Berg2.2	5.0	12.8	5.0
Berg2.3	11.7	24.6	11.7
Berg3.1	10.0	43.2	10.0
Berg3.2	8.8	42.9	8.8
Berg3.3	8.7	55.3	8.7
Berg3.4	8.6	83.6	8.6
SAP.1	21.3	140.9	21.3
SAP.2	17.6	31.0	17.6
NAP.1	7.8	12.2	7.8
PB.1	14.0	69.2	14.0
RK.1	3.7	23.6	3.7
RK.2	8.3	34.5	8.3
RK.3	3.4	33.7	3.4
Average over all typical farms	**8.6**	**39.8**	**8.6**

The net disposable income is defined as the gross income minus direct allocateable variable costs, overhead costs, household expenses, water purchases from the DWAF and transaction costs when trade is permitted. The overhead expenses do not include depreciation, which is a non-cash expense. Long, medium and short-term interest and capital redemption are however included and therefore indirectly provide for depreciation costs. The NDI per m^3 can be regarded as a measurement of water-use efficiency by the agricultural sector. The NDI per m^3 of irrigation water per typical farm varies substantially between the farms. The highest is recorded for SAP1; this is not surprising due to the value added to wine grapes by making wine in their own cellars and marketing it under their own labels rather than selling the wine grapes to co-operative wine cellars.

SAP2 has the second highest NDI per m^3 caused by specialised olive production, followed by PB (diversified fruit production). The average NDI per m^3 over all regions is approximately R10.5 per m^3 of irrigation water.

Table 5.7: Net disposable income per m^3 per irrigation region (2000)

Region	**BASE (R per m^3)**	**BASEOPT (R per m^3)**	**PMPOPT (R per m^3)**
Berg1	8.5	53.8	8.5
Berg2	9.2	21.9	9.2
Berg3	8.8	58.7	8.8
SAP	20.3	109.3	20.3
NAP	7.8	12.2	7.8
PB	14.0	69.2	14.0
RK	4.5	32.8	4.5
Average all regions	**10.5**	**51.1**	**10.5**

The results in Table 5.7 suggest that for this particular model, an approach without PMP would have lead to a gross overestimation of the NDI per m^3 for the irrigators along the Berg River. This also illustrates the point made by Backeberg (1994) that many alternative farm plans developed with models for irrigation planning in South Africa were far removed from what farmers did in the real world situation. The NDI per m^3 is more than five times higher without (BASEOPT) than with calibration constraints because of the "ill-posed" model definition.

5.3.4 Employment by the agricultural sector

The regional labour requirements are presented in Table 5.8. It was pointed out in Chapter 4 that labour use was not incorporated as a restriction in the model specification but rather to calculate the amount of labour used by the agricultural system. In Chapter 3 it was pointed out that according to the survey data irrigation farms require approximately 0.33 permanent and 0.28 casual labourers per ha.

Table 5.8: Regional labour requirements (2000)

Regional permanent labour use	**BASE Labourers**	**BASEOPT Labourers**	**PMPOPT Labourers**
Berg1	850	1840	850
Berg2	1787	1078	1787
Berg3	666	1675	666
SAP	277	784	277
NAP	481	197	481
PB	593	1337	593
RK	563	1370	563
Total	**5217**	**8280**	**5217**
Permanent labour use per ha irrigated	**0.39**	**0.62**	**0.39**
Regional casual labour use			
Berg1	1785	2749	1785
Berg2	4981	1626	4981
Berg3	1137	2480	1137
SAP	281	1181	281
NAP	1660	298	1660
PB	1255	2019	1255
RK	1266	3901	1266
Total	**12364**	**14255**	**12364**
Casual labour use per ha irrigated	**0.91**	**1.07**	**0.91**

However, most of these farms contract labourers for pruning, harvesting and other contract work. These labour requirements were not reflected in the survey data but were incorporated in the crop budgets. If the "casual" labour in Table 5.8 (BASE and PMPOPT) is converted to per ha irrigated land, the requirement per ha irrigated land will be 0.91 labourers per ha. This figure is more realistic than the 0.28 recorded in the survey data.

Table 5.8 clearly shows that contract labour makes a substantial contribution to the total labour use. Considering that approximately 13 500 ha are irrigated in the Upper-Berg River this means that approximately 4 455 permanent labourers are employed in the whole Upper-

Berg River, according to the survey data. The deviation in the model is therefore approximately 15 percent with regard to permanent labour. It must also be pointed out that for the purpose of this study only relative changes with regard to labour requirements are considered.

5.3.5 Agricultural water usage

Table 5.9 shows the water usage per aggregated typical farm. It is clear that the PMP model (PMPOPT) calibrates to almost the exact observed water usage.

Table 5.9: Water usage per aggregated typical farm (2000)

Water demand (1000m^3)	BASE	BASEOPT	PMPOPT
Berg1.1	590	533	590
Berg1.2	440	405	440
Berg1.3	487	380	487
Berg1.4	2192	2132	2192
Berg1.5	1801	1795	1801
Berg1.6	6488	7187	6488
Berg2.1	3162	2947	3162
Berg2.2	6049	5514	6049
Berg2.3	11990	10864	11990
Berg3.1	1289	1390	1289
Berg3.2	1114	1259	1114
Berg3.3	5607	5322	5608
Berg3.4	2056	2374	2057
SAP.1	1855	1855	1855
SAP.2	749	749	749
NAP.1	5902	5902	5902
PB.1	6683	6683	6683
RK.1	965	1058	965
RK.2	1510	2376	1510
RK.3	4543	6038	4543
Total	**65470**	**66763**	**65472**

Agriculture uses approximately 65 million m^3 of water per annum. This includes water from the Theewaterskloof Dam (summer allocation), a winter allocation for the Riebeek-Kasteel irrigation area as well as winter water extracted by riparian users to fill their farm dams and to irrigate winter crops. Of all the typical farms, Berg2.3 has the largest table grape component in the crop combination. Table grapes use approximately 9 600 m^3 per ha per annum, 35 percent more than wine grapes. This explains the high aggregated water use for this typical farm. A similar result is reflected in the regional water use (see Table 5.9) where the Berg2 region uses more water than any of the other regions.

Table 5.10 presents the water usage per irrigation region. The water use does not differ substantially between the three analyses. The main difference in the objective function in the BASE and BASEOPT analysis can therefore be contributed to the unrestrained expansion in dryland wine grapes, which was pointed out earlier in this chapter. With PMP this does not happen with either the dryland crop activities or the irrigation crop activities.

Table 5.10: Water usage per irrigation region (2000)

Water demand (million m^3)	BASE	BASEOPT	PMPOPT
Berg1	12.0	12.4	12.0
Berg2	21.2	19.3	21.2
Berg3	10.1	10.3	10.1
SAP	2.6	2.6	2.6
NAP	5.9	5.9	5.9
PB	6.7	6.7	6.7
RK	7.0	9.5	7.0
Total	**65.5**	**66.8**	**65.5**

Although Berg1, Berg2 and a part of Berg3 are in the higher rainfall areas they consume the most water. However, these irrigation regions are the oldest and development is reaching maturity. Expansions in the SAP, NAP, PB and RK regions are also restricted by the pump capacity of the schemes, which can only be increased through high capital expenditure. All the schemes are already pumping at almost full capacity during certain times of the year (December, January). The most likely users to buy water are therefore the Berg3 region, the riparian users.

5.3.6 Urban water usage

Table 5.11 shows the urban water usage per use sector. It is clear that "other households" consume most of the water followed by gardening and unaccounted water. The unaccounted water is equal to the combined usage of commercial and industrial water. It was pointed out in Chapter 3 that this is a highly controversial issue. The unaccounted for water represents water losses through pipe leaks, leaking taps, mainline pipe bursts etc. and renders considerablee scope for improvement in the urban water-supply network.

Table 5.11: Water usage per urban use sector (2000)

Water demand (million m^3)	BASE	BASEOPT	PMPOPT
Poor households	31.0	31.0	31.0
Other households	74.4	74.4	74.4
Gardening	68.2	68.2	68.2
Commercial	18.6	18.6	18.6
Industrial	40.3	40.3	40.3
Council	18.6	18.6	18.6
Unaccounted water	58.9	58.9	58.9
Total	**310.0**	**310.0**	**310.0**

It was pointed out in the introduction of this chapter that the PMP parameters of water supply to the urban sector were included in all three analyses. With the PMP parameters all the analyses calibrate to the exact observed urban usage. Table 5.12 shows the seasonal usage for urban water. Peak water usage occurs during December and January.

Table 5.12: Monthly water usage for all urban sectors (2000)

Monthly demand (million m^3)	BASE	BASEOPT	PMPOPT
January	35.3	35.3	35.3
February	30.4	30.4	30.4
March	32.3	32.3	32.3
April	25.0	25.0	25.0
May	21.9	21.9	21.9
June	18.9	18.9	18.9
July	17.7	17.7	17.7
August	18.6	18.6	18.6
September	19.7	19.7	19.7
October	26.9	26.9	26.9
November	29.0	29.0	29.0
December	34.3	34.3	34.3
Total	**310.0**	**310.0**	**310.0**

5.3.7 Water supply and demand balance

A summary of the water supply sources and water usage is presented in Table 5.13. The agricultural sector does not use the full storage capacity of the farm dams. The reason is the assumption that farm dams only fill up a certain percentage of the capacity during the winter months (rainy season). This percentage varies between the high rainfall upper reaches of the river basement and the dryer lower reaches (varying between 65 percent and 90 percent).

It is clear from Table 5.13 that the agricultural sector used almost 94 percent of the summer water allocation[3] during the 2000 season. It was pointed out in Chapter 3 that according to the previous Water Act (1956) the total agricultural water entitlement from the Theewaterskloof Dam was approximately 75 million m^3. Within the new water policy regime it is doubtful if agriculture will ever receive the full 75 million m^3 entitlement. For the purpose of the base analysis it was therefore assumed that within the new water policy regime they would only receive 43.6 million m^3 based on the present water availability, present water use, and the growth in urban demand. The next section of this chapter will point out how vulnerable this makes the agricultural sector to water restrictions based on administrative water allocation policies. The agricultural sector's gross water usage is 40.7 million m^3 for summer water (Theewaterskloof Dam water). From this figure a 25 percent river conveyance loss must be subtracted to arrive at a net water usage of about 30.5 million m^3. Approximately 11.9 million m^3 winter water is used for filling up farm dams during the winter and for winter irrigation. The model specifies that winter water can only be used to fill up a capacity that is equal to the full storage capacity minus the intake from natural runoff.

The urban sector utilises the full 125 million m^3 allocation from the Theewaterskloof Dam. The remaining 185 million m^3 of water is obtained from other dams as described in Chapter 3.

Table 5.13: Water usage and supply summary (2000)

Agricultural water usage	**BASE (Million m^3)**	**BASEOPT (Million m^3)**	**PMPOPT (Million m^3)**
Total summer water allocation	43.6	43.6	43.6
Summer allocation utilised	40.7	43.4	40.7
Total winter water allocation	26.6	26.6	26.6
Winter allocation utilised	11.9	11.1	11.9
Winter allocation utilised to fill farm dam	3.2	3.4	3.4
Winter allocation utilised for irrigation	8.7	7.7	8.5
Farm dam water storage capacity	17.2	17.2	17.2
Farm dam water utilised	16.0	16.3	16.2
Total volume used: all sources	**65.5**	**67.4**	**65.5**
Urban water usage			
Total allocation: Theewaterskloof	125.0	125.0	125.0
Allocation used from: Theewaterskloof	125.0	125.0	125.0
Other dams	185.0	185.0	185.0
Total volume used: all sources	**310.0**	**310.0**	**310.0**

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[3] Allocation refers to the annual allocation by the DWAF depending on water availability. Entitlement refers to the entitlement prior to the new Water Act, 1998. Although agriculture is at the moment still entitled to the water, this may change when the licensing process proceeds in 2001.

Table 5.14 shows that the average water price for urban users is R7.79 per m^3 of water. The model only provides for a summer price and a winter price for water. At the time of the writing of this thesis the CMC was in the process of introducing a new block tariff for water. However this information is not available and for the purpose of this research it was regarded as sufficient to only use two base prices. This is an oversimplification of water pricing in the urban sector. It should be noted that the model does not simulate individual urban water users' behaviour but rather that of water-use sectors. In order to introduce block tariffs for water (tariffs based on market forces) it would be necessary to work with the per capita consumption per user sector and aggregate again to the sector level. This will increase model complexity considerably.

Table 5.14: Average urban price per urban use sector

Water price (Rand per m^3)	**BASE (R per m^3)**	**BASEOPT (R per m^3)**	**PMPOPT (R per m^3)**
Poor households	8.76	8.76	8.77
Other households	8.76	8.76	8.77
Urban gardening	8.77	8.77	8.77
Commercial	8.77	8.77	8.77
Industrial	8.77	8.77	8.77
Council	8.77	8.77	8.77
Unaccounted for water	0.95	0.95	0.95
Average urban price	**7.79**	**7.79**	**7.79**

5.4 Conclusion

Models have a strong role to play in water allocation and water policy analysis, particularly in the case of water markets where reliable time series data are absent. The PMP technique employed in this study proves to be very efficient for calibrating linear as well as non-linear models to reproduce the exact base analysis without calibration constraints. The solution of the PMP approach is based on the derivation of non-linear production functions for agricultural production activities based on observed resource use data. The same applies to the derivation of a water supply function for supplying water to satisfy the urban demand. This is done through the use of dual values produced by a model with calibration constraints.

The structural model of water demand and supply developed in Chapter 4 includes the effect of water-user reaction towards water policy impacts such as an administrative versus market allocation mechanisms, water scarcity and shifts in the long-run urban demand for water. The analysis proves that the model is valid to simulate a potential water market and that the model is a fairly accurate presentation of the actual situation in the Upper-Berg River.

The efficiency of the technique for analysing the effect of trade on the allocation of water is discussed in the following chapters.

Chapter 6

THE EFFECT OF TRADE ON EFFICIENCY AND THE OPTIMAL ALLOCATION OF WATER

6.1 Introduction

Market systems have a tendency to defuse political conflict, largely because anyone who obtains a resource must pay the prior owner a price that satisfies that owner. Market transfers are voluntary transactions in which traders will only participate if they believe that it is in their best interest given the alternative opportunities available to them. Administrative allocation, in contrast, often generates intense conflicts because granting a water right to one user necessarily precludes another and there is no automatic pecuniary compensation for the basin of origin. Water markets change the nature of bargaining over water transfers. Instead of political wrestling, with the losing region defeated by the winning region, the bargaining can become a process of mutually advantageous exchange (Young, 1986).

If water is an economic good, then it should be possible to govern its allocation through the market. For many years, it has been widely recognised in the literature that in the absence of markets it is difficult, if not impossible, to evaluate the real demand for water-related services because demand functions cannot be estimated in such a situation. Numerous elaborate and unsatisfactory substitutes have been suggested in the place of markets and the signals for efficiency in investment decision-making which they provide. Many authors (e.g. Anderson, 1982, 1983, 1985; Easter and Hearn, 1995; Colby *et al*, 1993; Colby, 1988; Challen and Petch, 1997; Young, 1986) are of the opinion that all these substitutes have in common that they provide only poor, if not incorrect signals, that they are essentially arbitrary and that they provide no real solution to the problem of achieving efficient allocation of water. The only solution is to place as great a reliance as possible on prices and, therefore, on markets in the process of allocating of water and the related investments in productive services. If efficiency is the goal, then the role of administrative allocation must be restricted to those few areas where markets cannot be developed and to the regulation of natural monopolies.

Because of the information problem, there seems to be little hope that administrative approaches can allocate water even with only minimal efficiency among the processes that result in marketable goods. It is not reasonable to expect a staff and a board to know the value of water in every water use; such knowledge is necessary in order to know the economic efficiency of each board decision. The solution to the information problem will likely necessitate applying a market-like process for allocating water to produce market goods. The regulatory approach and the limited funds can then be focused on the areas where they are needed, which is in deciding water needs for the non-market goods (Young, 1986).

According to Maasdorp (1992) there is scarcely an economist of any calibre today in Eastern Europe or the former Soviet Union who would defend central planning as an economic system. It is widely recognised that the system has been woefully inefficient. In fact, it is impossible to plan efficiently from the centre, and the bigger and more open the economy is, the more impossible it becomes. For technical reasons alone, central planning is impossible, a fact which non-economists often fail to grasp. If a model is technically inoperable, then politicians seeking to implement it are courting disaster for their country.

The purpose of this chapter is to explore the role that water markets can play in improving efficiency and in allocating water between competitive uses. Although the infrastructure to trade winter water to the urban sector does not exist at present, it was included in the model to show what its effect will be. The infrastructure will have to consist of a weir and a pump station in the vicinity of the Robertsvlei tunnel outlet to be linked with the present tunnel water supply system of the CMC (see section 3.4.1).

Approximately 35 to 40 percent of the urban sector's water demand is for winter water. If they can buy winter water rights from the agricultural sector it will be possible to store some of the winter water that they normally extract from the Theewaterskloof Dam for use in the summer. Such a strategy can make an important contribution to risk management, with a minimum impact on the ecology, since the Theewaterskloof Dam will have more water in storage in a dry year. The section below gives a description of the scenarios that will be tested. All these scenarios are analysed under trade and no-trade conditions. This is followed by the results. The chapter is concluded with a summary of the most important findings.

6.2 Scenarios to be tested

The gains in efficiency are illustrated in a very simple way by comparing the PMPOPT (no trade) analysis as described in Chapter 5 to exactly the same model but with trade permitted (PMPTR1).

Water shortages are a looming threat in the Upper-Berg River region. According to Van Zyl (2000) these shortages will increase in future and water restrictions will be the rule rather than the exception. These restrictions already manifested themselves on 1 November 2000 when a 10 percent restriction on all water sources in the wider Cape Town area were instituted by the DWAF. Van Zyl (2000) is of the opinion that even with normal rainfall these restrictions will increase in future because the growth in demand for urban water outstrips the growth in the supply of water. Also, as stated in Chapter 3, the possibilities for water augmentation schemes are limited due to the lack of suitable dam sites (ecological impact) and a lack of funds to build new schemes. The role that potential water markets could play in alleviating water restrictions was examined by analysing the following water restriction scenarios:

Base1: No trade, the same as PMPOPT

Resntr10: No trade with a 10 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

Resntr20: No trade with a 20 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

Resntr30: No trade with a 30 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

Resntr40: No trade with a 40 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 50 percent of the base.

Base2: The same as PMPOPT but the no-trade restriction is released. The fixed transaction cost between agriculture and the urban sector is twice as high as between irrigators. However, the variable transaction costs are identical.

Restr10: Trade with a 10 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

Restr20: Trade with a 20 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

Restr30: Trade with a 30 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

Restr40: Trade with a 40 percent restriction on all water supplies and entitlements. The minimum urban sector demand is 70 percent of the base.

The minimum urban demand specification is imposed because of the vital nature of water as a life-sustaining commodity. Neither scenario permits the building of new water supply schemes in the short run. When no trade is possible it becomes impossible for the Water Services Authority (WSA) of the CMC to supply 70 percent of the base year demand for water. It was therefore necessary to relax the 70 percent specification to 50 percent in the **Resntr40** scenario to ensure feasibility in the model.

To test the market as a water allocation mechanism when growth in urban water demand outstrips supply, the expected growth in the urban demand was modelled from the current levels to 2020 levels. These are longer-term scenarios where new water supplies can be developed and where the agricultural sector can make structural adjustments. The following scenarios were simulated:

Basel: No trade. The same as PMPOPT but with a 10 to 25 percent increase in the base area available for irrigation water. An agricultural water allocation of 75 million m^3 based on the 1998 entitlement levels is available and an urban allocation from the Theewaterskloof Dam of 93 million m^3 also based on the original entitlements are available.

Urbntr20: No trade with a 20 percent increase in the base year urban demand

Urbntr40: No trade with a 40 percent increase in the base year urban demand

Urbntr60: No trade with a 60 percent increase in the base year urban demand

Urbntr80: No trade with a 80 percent increase in the base year urban demand

Base2: The same as **Basel** but the no-trade restriction is relaxed.

Urbtr20: Trade with a 20 percent increase in the base year urban demand

Urbtr40: Trade with a 40 percent increase in the base year urban demand

Urbtr60: Trade with a 60 percent increase in the base year urban demand

Urbtr80: Trade with a 80 percent increase in the base year urban demand

The results are discussed in terms of the impact on the welfare of urban consumers and the agricultural sector, water demand and supply, agricultural land use, the urban price of water and the values attached to water rights.

6.3 Efficiency of water markets

Efficiency of water markets is analysed by comparing the base analysis with the non-trade PMP model with the PMP base model where trade is permitted. The results are discussed in terms of the objective function parameters, irrigation area utilisation, water usage, and the value of water.

6.3.1 Objective function parameters

Table 6.1 represents the objective function parameters of the base solution with PMP but without trade (PMPOPT) and with trade (PMPTR1). The change in the objective function value is insignificant. However, the total NDI increases with 3.78 percent, indicating that the producer surplus increased because of trade. Also interesting to note is the decrease in the value of the PMP parameter.

Table 6.1: Objective function parameters

Objective function parameters (million Rand)	PMPOPT	PMPTR1	Deviation from PMPOPT
Objective function (million Rand)	7822	7846	0.30%
Consumer surplus	5097	5098	0.02%
Income from water sales by CMC	2320	2320	-0.03%
Total NDI	611	634	3.78%
Other water supply costs	-206	-205	-0.30%
PMP parameter value	4354	3961	-9.03%
Total	**7822**	**7846**	0.31%

The PMP parameter is an indication of inefficiencies in the system due to the fact that it is linked directly to the dual values of resources. The PMP parameter decreases because, when trade is permitted, water can flow from lower to higher values and an overall increase in the efficiency of water allocation occurs.

6.3.2 Irrigation area utilisation

Table 6.2 compares irrigation area utilisation between a trade and a no-trade regime. Although the total area under irrigation remains the same, deficit and supplemental irrigation areas decrease and are substituted by an increase in the area under optimal irrigation. Farmers therefore increase the value of their production by increasing the irrigation intensity.

Table 6.2: Irrigation area utilisation (ha)

Crop type	**PMPOPT**	**PMPTR1**	**Deviation from PMPOPT**
Long term crops: optimum irrigation	8107	11425	40.93%
Long term crops: deficit irrigation	763	154	-79.88%
Long term crops: supplemental irrigation	3234	526	-83.74%
Total long-term crops	12104	12104	0.01%
Vegetables: optimum irrigation	1432	1432	0.01%
Total ha	**13536**	**13536**	0.01%

6.3.3 Water usage

Table 6.3 presents the usage of the summer water entitlement from the Theewaterskloof Dam. When trade is permitted the total agricultural summer water usage increases by 2.8 percent.

The increase in demand for summer water can be attributed to the trade of "sleeper rights" (unused water rights) as well as a change to higher intensity irrigation. The increase occurs in the Berg1 and Berg3 regions. This is consistent with the findings of other researchers elsewhere (e.g. Colby, 1988 and 1990; Bransom and Eigenraam, 1996; Challen *et al*, 1996) who found that when a water market is introduced, unused ("sleeper rights") are the first to be traded and it is therefore possible that water usage will increase in the short run. However, as soon as water scarcity situations arise, the market mechanism sends the signals to users to use their water more efficiently.

Table 6.4 presents the usage of winter water, which undergoes a substantial increase.

Table 6.3: Summer water usage (m^3)

Summer water right	PMPOPT	PMPTR1	Deviation
Berg1.1	351696	351699	0.00%
Berg1.2	305001	305001	0.00%
Berg1.3	170933	188601	10.34%
Berg1.4	1493179	1493179	0.00%
Berg1.5	1415692	1415692	0.00%
Berg1.6	2420474	2867068	18.45%
Berg2.1	2260082	2260082	0.00%
Berg2.2	3611916	3611916	0.00%
Berg2.3	8126888	8126888	0.00%
Berg3.1	1085133	1192969	9.94%
Berg3.2	890259	1064360	19.56%
Berg3.3	4464054	4590051	2.82%
Berg3.4	1493443	1766048	18.25%
SAP.1	1016549	1016549	0.00%
SAP.2	416981	416981	0.00%
NAP.1	4360500	4360500	0.00%
PB.1	3962750	3962750	0.00%
RK.1	394940	394942	0.00%
RK.2	429060	429063	0.00%
RK.3	2048762	2048765	0.00%
Total	**40718300**	**41863110**	**2.81%**

Table 6.4: Agricultural usage of winter water

Winter water demand	PMPOPT	PMPTR1	Deviation
Berg1.1	159817	269218	68%
Berg1.2	102937	200833	95%
Berg1.3	135256	135256	0%
Berg1.4	428874	1456325	240%
Berg1.5	240025	901229	275%
Berg1.6	1734700	4020213	132%
Berg2.1	649264	1257624	94%
Berg2.2	1684562	1684562	0%
Berg2.3	2806233	5501299	96%
Berg3.1	203588	508894	150%
Berg3.2	223902	409288	83%
Berg3.3	1143699	2994731	162%
Berg3.4	390457	880042	125%
SAP.1	0	0	0%
SAP.2	0	0	0%
NAP.1	0	0	0%
PB.1	0	0	0%
RK.1	295299	690242	134%
RK.2	474618	903682	90%
RK.3	1220263	3269029	168%
Total	**11893495**	**25082467**	**111%**
Used for irrigation or trade	8531822	21923188	156.96%
Used for filling up farm dams	3361673	3159279	-6.02%

This is not surprising. The increase can be explained through an increase in the area under optimal irrigation (winter water contributes 15 to 20 percent of total optimum irrigation intensity water requirements) and by the urban sector buying winter water (lower scarcity value) from farmers in order to conserve scarce summer water. The gains in efficiency are manifested when a real scarcity situation exists (a detailed discussion of this is provided in Section 6.4).

Table 6.5 summarises total agricultural water usage. The impact of trade is an overall increase of 12.3 percent in the volume of water used as soon as a water market is introduced.

Table 6.5: Summary of regional water usage (million m^3)

Region	PMPOPT	PMPTR1	Deviation from PMPOPT
Berg1	12.0	13.1	9.25%
Berg2	21.2	23.7	11.68%
Berg3	10.1	10.1	0.00%
SAP	2.6	4.1	57.82%
NAP	5.9	6.4	8.60%
PB	6.7	9.1	36.51%
RK	7.0	7.0	0.00%
Total	**65.5**	**73.5**	**12.28%**
Summer water use increase	**40.7**	**41.9**	**2.81%**
Winter water use increase	**11.9**	**25.1**	**111%**

Tables 6.4 and 6.5 indicate that the increase in water use occurs mainly from winter (111 percent) and not summer water. Winter water is less scarce than summer water. The summer water use only increases by 2.81 percent. This means than even though there is not a real scarcity situation in the base analysis, the market signals summer water to be scarcer than winter water. In the model this is done by the shadow values on the input rows of the water supply equations. Table 6.6 shows the urban water supply sources. Approximately 6.3 million m^3 water will be traded if a water market will be instituted for 2000/2001 water supply conditions and if the infrastructure existed for winter water to be traded.

Table 6.6: Urban water supply sources

Source	PMPOPT	PMPTR1
Total allocation – Theewaterskloof	125.0	125.0
Allocation bought from Theewaterskloof	125.0	125.0
Obtained through temporary trade	0.0	6.3
Other dams	185.0	178.7
Total m^3 of water used: all sources	310.0	310.0

Although only 1.64 percent of the total volume of water consumption (383.5 million m^3) is being traded when a water market is introduced, it is clear that just the fact that water is tradable will send out important messages.

6.3.4 Water values

Table 6.7 shows the marginal value of the present allocation of water users. In a no-trade regime, huge differences in the value of water clearly exist among users. This is caused by inefficiencies in the system. A large marginal value indicates a shortage and hence under-use of water, while a small or zero value indicates a relative abundance of water. A water market removes shortages as far as possible and all water users will, in the absence of imperfections, attach the same marginal value to water. Differences do however occur because of differences in the transaction costs and/or when other restrictions prevent the use of more water (e.g. land, pump capacity). In the trade scenario (PMPTR1) the transaction costs for transfers between agriculture and the urban sector were higher than for trade within the agricultural sector.

Table 6.7: Marginal value of present water allocation

Agricultural present allocation value	PMPOPT	PMPTR1
Berg1.1	0.0	0.3
Berg1.2	11.7	0.3
Berg1.3	0.0	0.0
Berg1.4	8.0	0.3
Berg1.5	20.2	0.3
Berg1.6	0.0	0.0
Berg2.1	12.7	0.3
Berg2.2	5.7	0.3
Berg2.3	19.3	0.3
Berg3.1	0.0	0.0
Berg3.2	0.0	0.0
Berg3.3	0.0	0.0
Berg3.4	0.0	0.0
SAP.1	17.6	0.3
SAP.2	3.3	0.3
NAP.1	13.6	0.3
PB.1	12.1	0.3
RK.1	0.0	0.0
RK.2	0.0	0.0
RK.3	0.0	0.0
Urban	10.1	1.4
Median agricultural value	**1.6**	**0.3**
Maximum value	**20.2**	**0.3**
Minimum value	**0.0**	**0.0**

The differential transaction costs present one reason for the difference in the value of water between agriculture and the urban sector. There is, in addition market interference in the sense that the model specifies that the 70 percent of the urban sectors base demand must be satisfied. This may also have and impact on the valuation of water.

6.4 Results of water restriction scenarios

Results of the water restriction scenarios are presented in Figure 6.1 to Figure 6.12 and Table 6.8 and 6.9. The detailed results can be found in Appendix C (Table C.1 to Table C.4). Water restrictions impose a water scarcity, which implies that the value of water will increase for all users. In the absence of trade it is not possible for the urban or the irrigation sector to augment their water supplies through trading or any other source. The only options for the agricultural sector are to improve water use efficiency or to irrigate a smaller area with the available water.

6.4.1 Objective function parameters

Figure 6.1 shows the decline in welfare as the water restrictions intensify. However, when trade is possible the impact is reduced due to the buffering effect of trade. It is then possible for water to be reallocated from lower-value uses to higher-value uses.

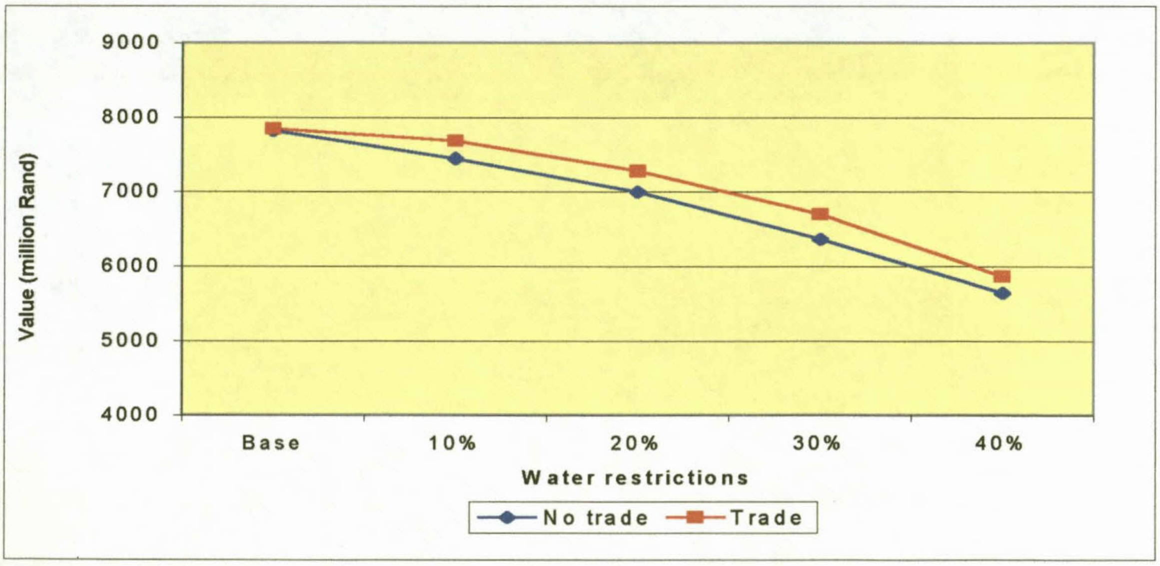

Figure 6.1: Objective function value (million Rand)

Figure 6.2 shows the decline in the consumer surplus. The trend is similar to that of the objective function value.

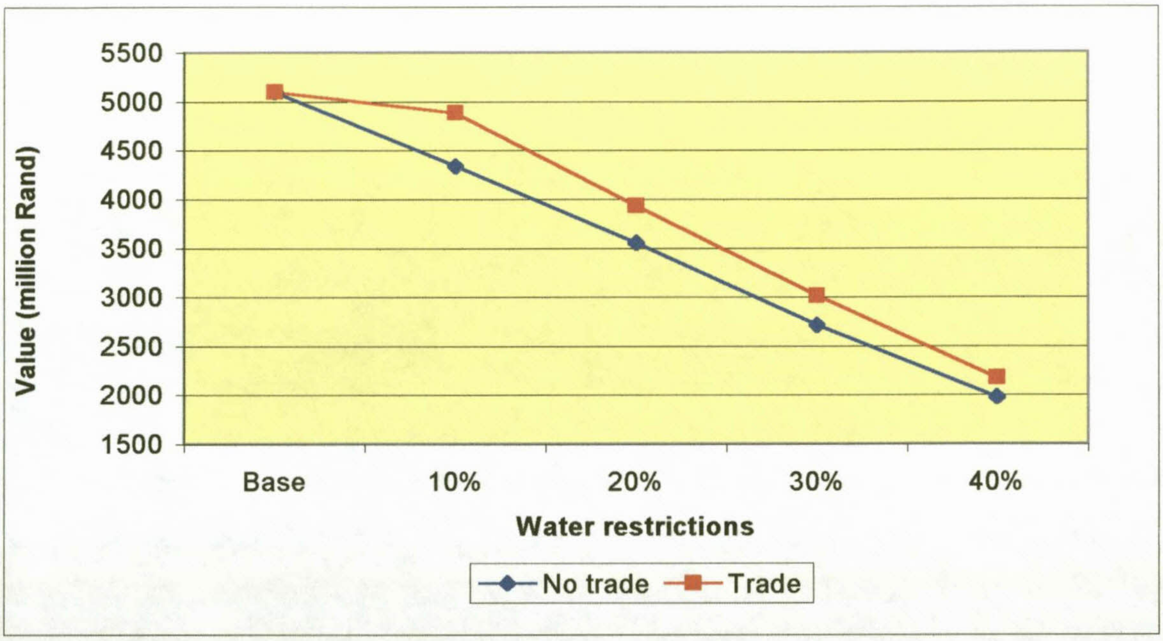

Figure 6.2: Consumer surplus (million Rand)

If trade is not possible, the decline in the consumer surplus is more drastic than with trade; the scarcity value of the water is reflected in the increased water price for urban consumers and as restrictions are imposed, water sales to the urban sector decrease.

The "price" of urban water will always be determined in the form of a tariff. However, the water utility will have to take rising supply costs into account when determining tariffs. In a water market these costs are lower because reallocation of water can take place at a lower cost than building new supplies (see Figure 6.3). Water markets remove some inefficiencies from the system. The model does not consider increases in the efficiency of water supply authorities. However, rising values and the prices of water provide incentives to increase efficiencies, especially by reductions in the volume of unaccounted water. It was pointed out in Chapter 4 that the "price" of urban water is determined in the model as a function of the urban demand and the demand elasticity per urban use sector.

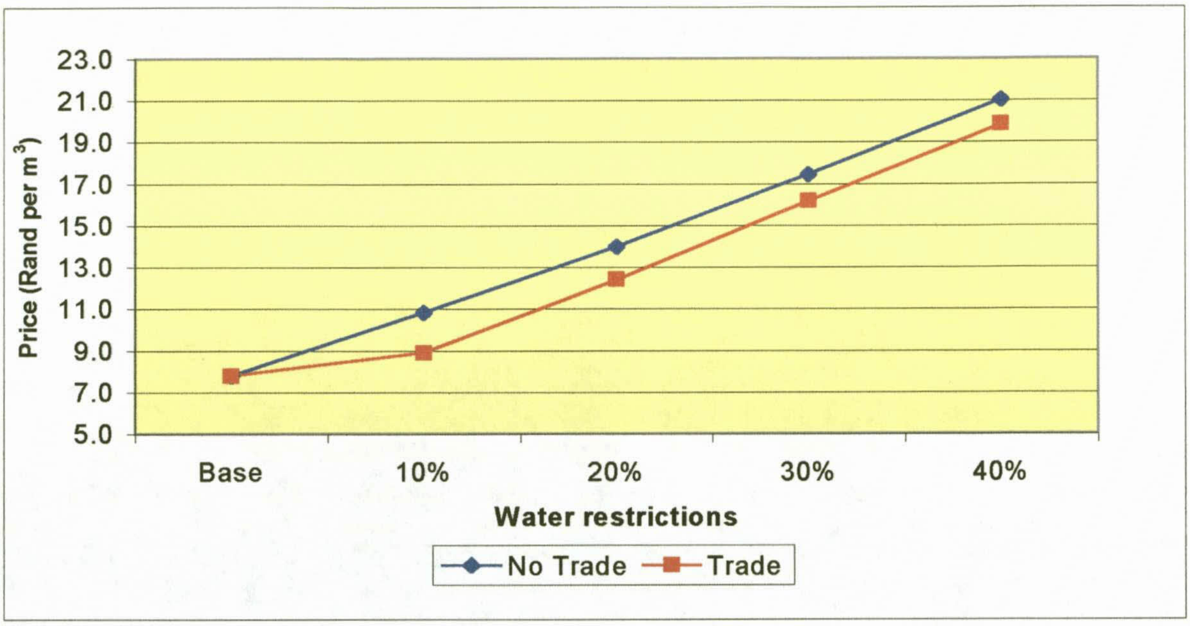

Figure 6.3: Average urban water price (Rand per m^3)

Figure 6.4 presents the total net disposable income of the agricultural sector under different scenarios. With a 10 percent restriction there is an initial adjustment as irrigators convert to lower irrigation intensities (deficit and supplemental). The NDI decreases less rapidly when trade is possible. At a 40 percent restriction it is no longer possible to combat the scarcity through trade and the NDI declines rapidly.

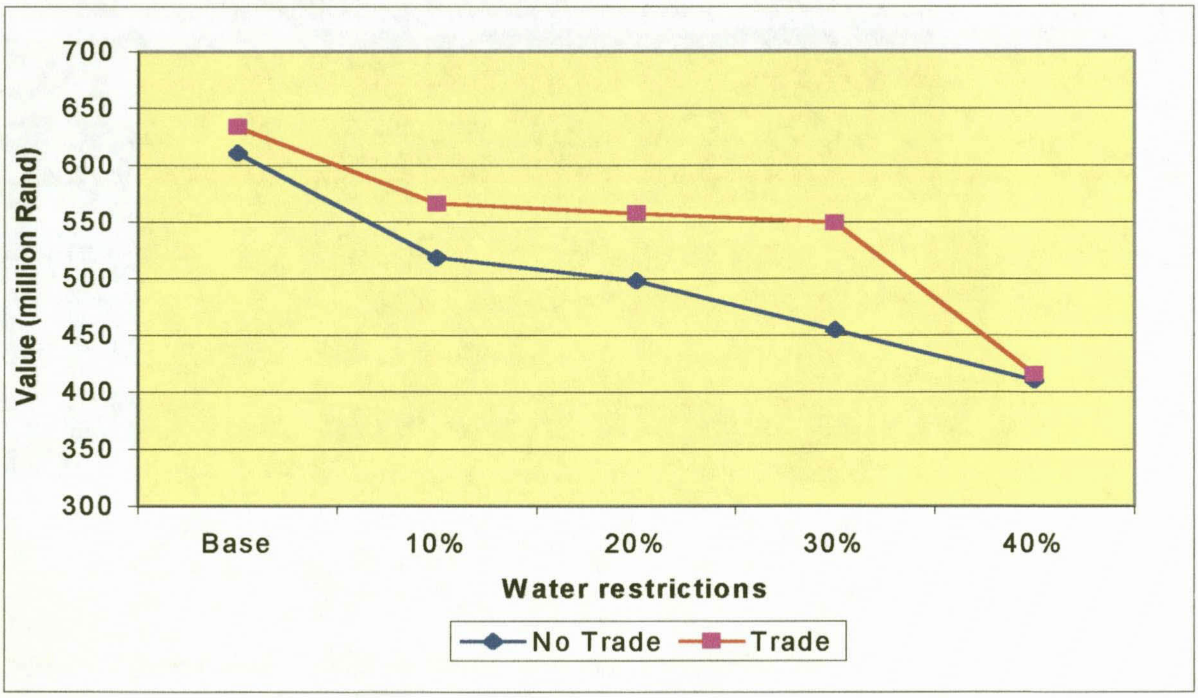

Figure 6.4: Total net disposable income (million Rand)

6.4.2 Impact of trade on water use efficiency

Figure 6.5 presents NDI per m^3 irrigation water. The lower NDI per m^3 of water with the base trade scenario occurs because within a water market, the initial reaction for farmers will be to use more water because more is available through trade. However, as water becomes scarcer a water market can induce more efficient water use by increasing NDI per m^3 of irrigation water. This adjustment already takes place when a 10 percent restriction is imposed. After this NDI stays relatively constant up to a 30 percent restriction and then starts to decline.

This result agrees with taht of Paget and Lategan (1986), who found that farmers could reduce irrigation intensity until it is 30 percent less than the optimal. After this level maintenance of production levels becomes very difficult. This is however, a generalisation because with certain crops, such as table grapes and some pome fruit, competition with regard to quality is very strict. These crops are very sensitive to lower irrigation intensities. With the no-trade option, efficiency is generally lower because of the lack of incentives to save water.

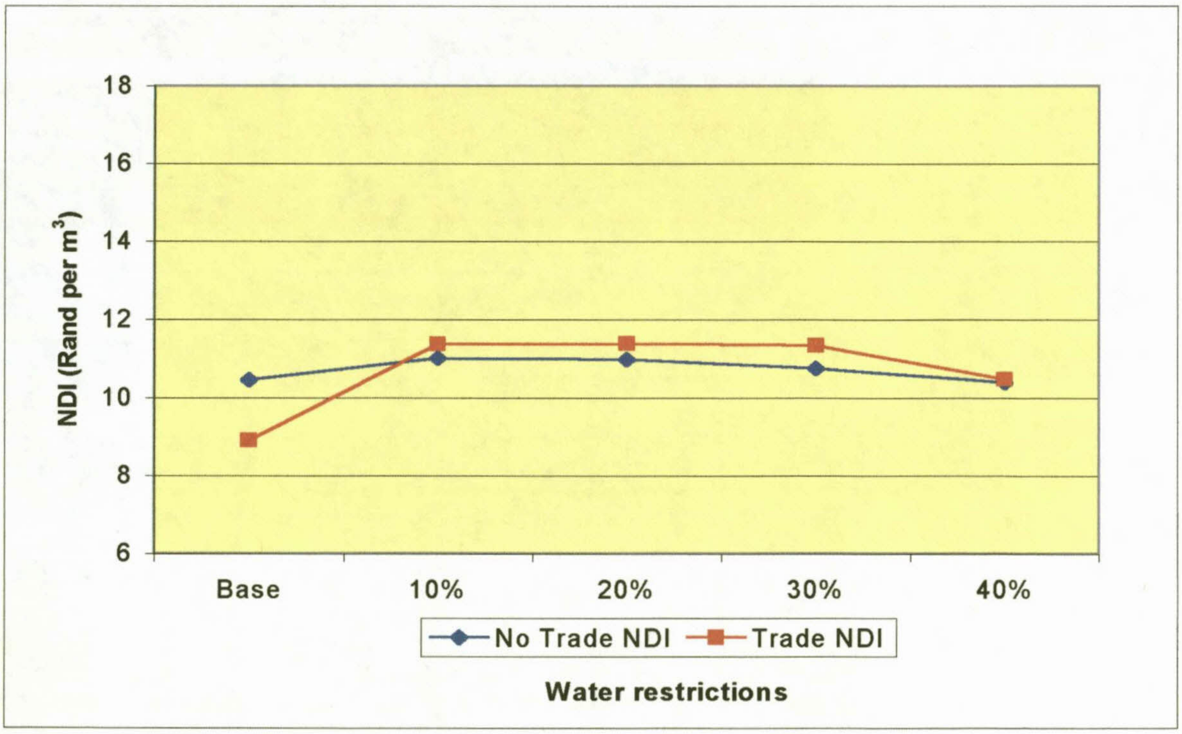

Figure 6.5: NDI per m^3 of irrigation water (Rand per m^3)

Table 6.8 represents the composition of irrigation intensities for the scenarios. With no water trade farmers tend to produce more crops under supplemental and deficit irrigation in the base scenario than with trade. When water scarcity sets in they produce more crops under supplemental and deficit irrigation because the impact of the restrictions is more severe than with trade.

Table 6.8: Irrigation intensity under different water scarcity scenarios (ha)

Item	No trade					Trade				
	Base	**10%**	**20%**	**30%**	**40%**	**Base**	**10%**	**20%**	**30%**	**40%**
Optimum	8107	2891	3158	2449	2043	11425	5208	5073	4689	2521
Deficit	763	2722	2089	2108	2214	154	1148	1247	1640	1647
Supplemental	3234	6443	6449	6644	6309	526	5748	5784	5773	6288
Total	12104	12056	11696	11201	10566	12105	12104	12104	12102	10456

When it is possible to trade, farmers can produce more crops under optimal irrigation because more water is available through trade. They can also change to lower intensity irrigation systems and sell water if they have surpluses. This is a direct effect of the rising opportunity cost of water and consistent with the work of Anderson (1982, 1983 and 1985).

6.4.3 Market allocation of water

Figure 6.6 presents the volume of water being traded within each user sector. There is clearly a negative correlation between trade within the agricultural sector and agriculture to urban trade. The initial reaction with a 10 percent restriction is decreased trade between farmers and increased trade to the urban sector.

However, in the short-term farmers' ability to make structural changes with long-term crops is limited and trade within the agricultural sector increases again in order to sustain production levels.

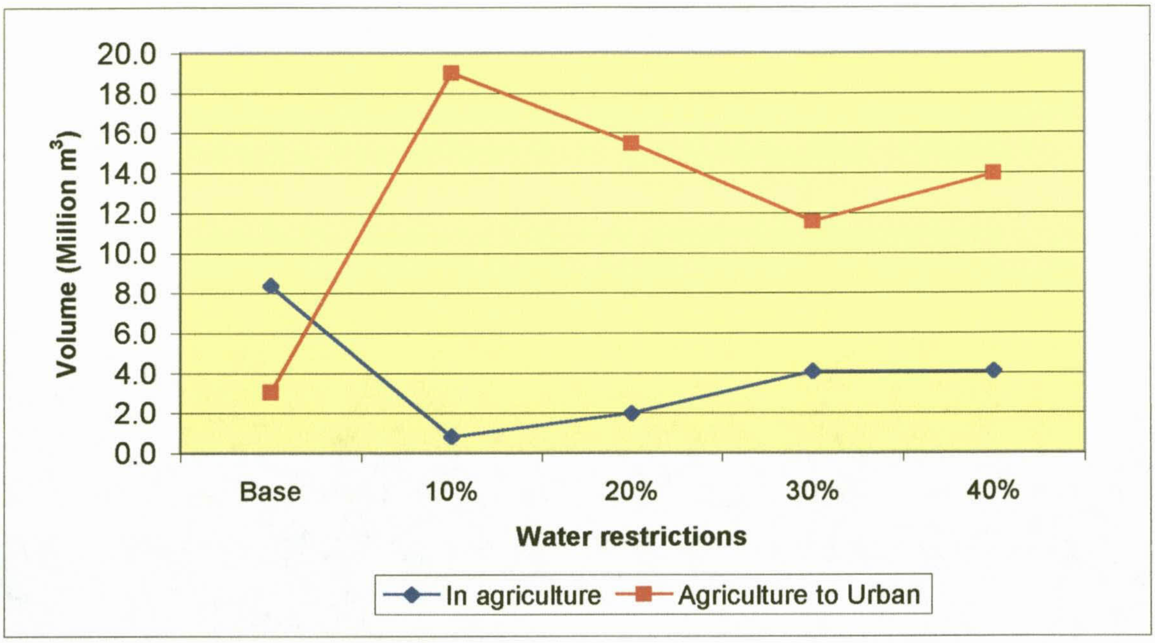

Figure 6.6: Water trade volume

Figure 6.7 presents the total volume of water traded as percentage of the total water usage. The trade volume increases as percentage of total water consumption. As water restrictions increase, in the base only 5 percent of the total usage for water is traded; this increases to over 9 percent when a 40 percent restriction is imposed.

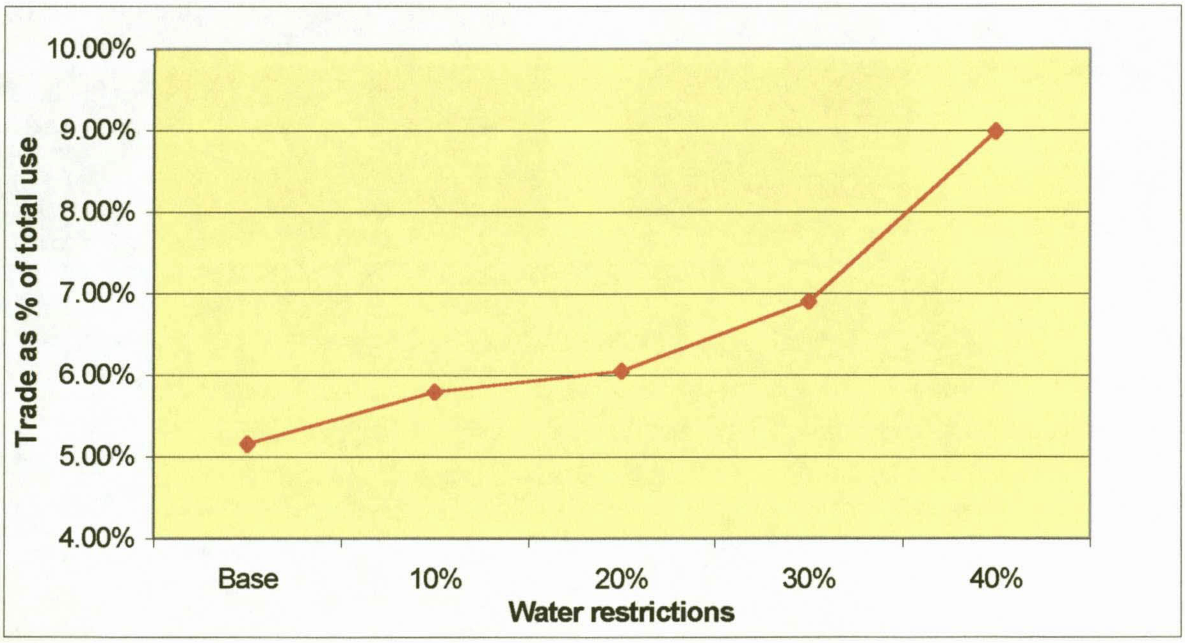

Figure 6.7: Trade as percentage of total demand

Figures 6.8 and 6.9 present the marginal value of water without and with trade respectively for each of the scenarios. Figure 6.8 indicates a large difference between the values of water in different uses in the absence of trade. This is indicative of non-optimal allocation of water.

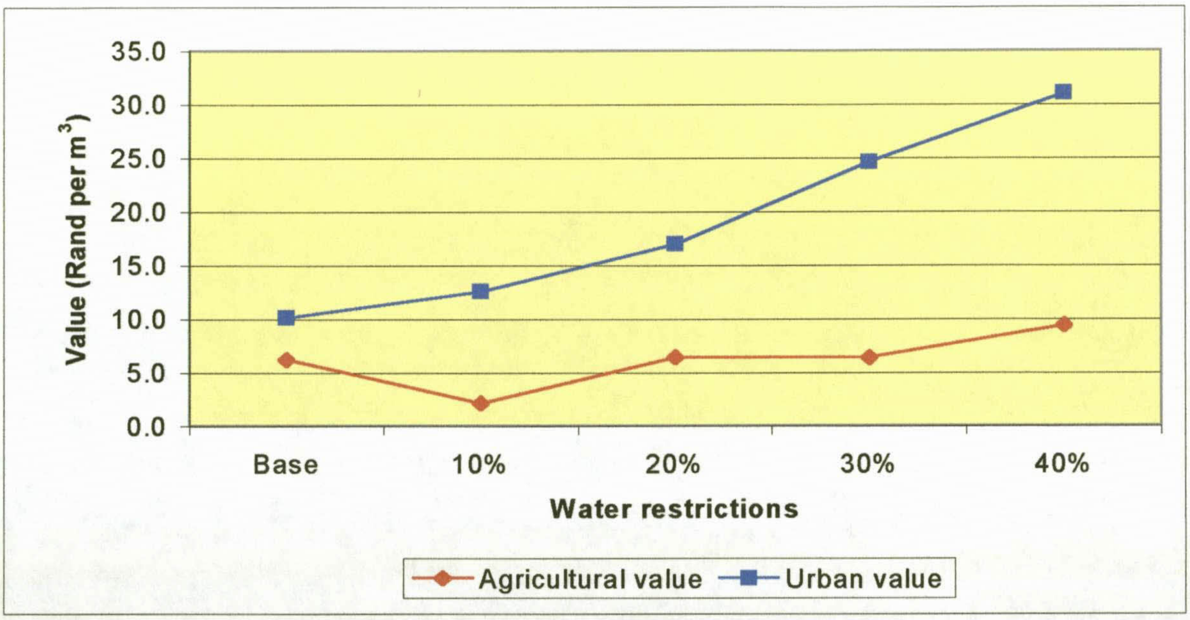

Figure 6.8: Marginal value of water without trade

Figure 6.9 shows that trade causes the marginal value of water of the different uses to be very close to each other, indicating close to optimal water allocation.

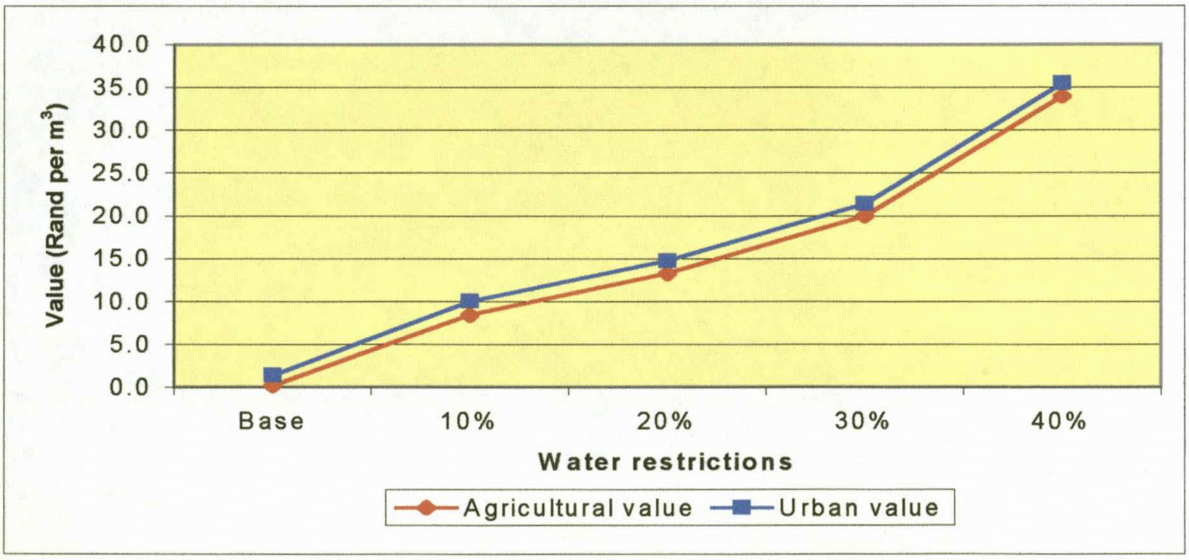

Figure 6.9: Marginal value of water with trade

Easter *et al* (1997) pointed out that once markets are introduced and property rights established in water, transfers of water rights can be expected to occur whenever the net benefits from a reallocation are positive, until marginal values, net of transaction and conveyance costs, are equalised among water users, uses and locations. Trade will continue until all water users are indifferent between buying and selling water rights. Market transactions are precipitated by differences in the value of water in alternative uses and locations, provided the differences are large enough to outweigh the transaction and transportation costs of obtaining water through the market. Water markets are unlikely to emerge, be active or operate effectively where water is in surplus and/or where there are alternative sources of low-cost water. It is for this reason that market activity often intensifies in periods of insufficient water supplies, while being less active or latent in periods of normal supply conditions.

The model measures the value of water by calculating the dual values in the water supply equations, as was also done by Archibald and Renwick (1998) as described in Chapter 2. The dual value of the water-use right constraint represents the marginal value of water. In water markets the water-use right constraint will always be binding at the optimum since no producer will purchase water unless he will use it productively and any producer with an unused portion of his or her allotment will be better off by selling it.

A continuous trade in water rights generates prices that by coordinating dispersed information and preferences indicate the opportunity cost of water or its relative scarcity. Price is an information-rich signal, which summarizes all information available to market participants and motivates appropriate levels of individual action in response to changing demand and supply conditions, thus performing the crucial rationing function in allocating resources to different uses and users. Thus, transferable water rights create a system of economic incentives in which those who have the best knowledge about returns to water, are encouraged to use that knowledge to allocate water to higher-value uses, and hence maximise the economic value obtained from the scarce resource with a minimum of bureaucratic apparatus (Cummings and Nercissiantz, 1994).

Figure 6.10 presents the total availability of water per ha and Figure 6.11 shows the total area under irrigation. With a tradable water regime farmers can maintain the area under irrigation for much longer before they have to start decreasing the area under production. This indicates that the market mechanism is efficient in reallocating water within agriculture during periods of water scarcity.

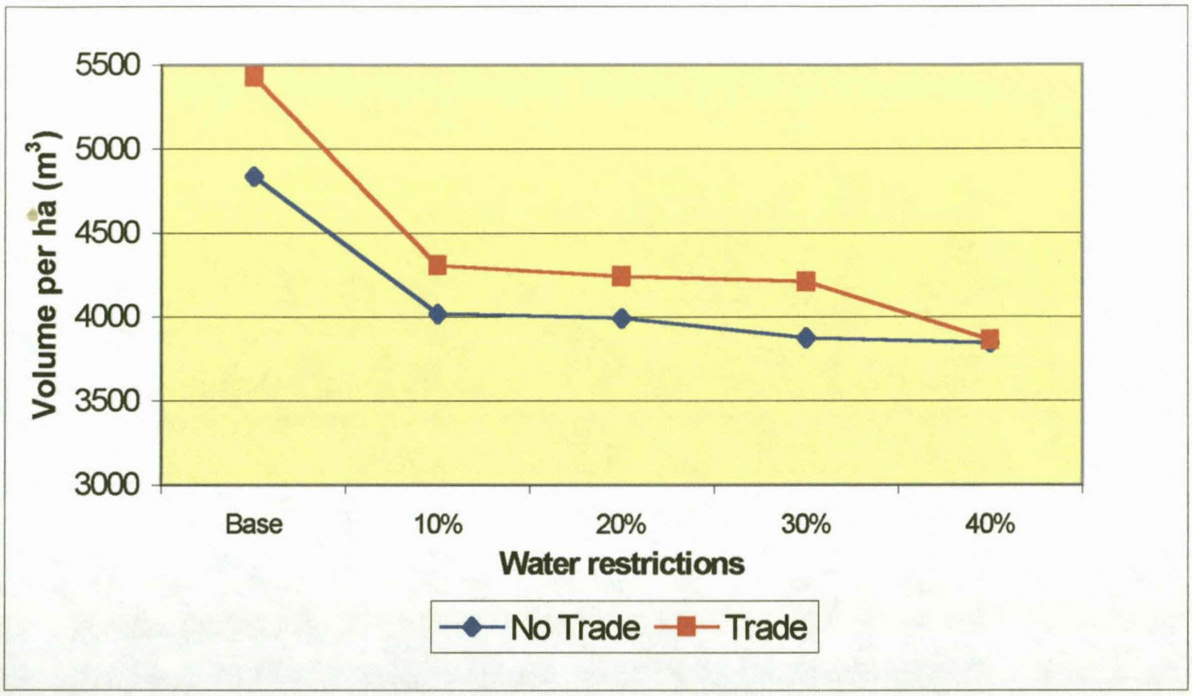

Figure 6.10: Water availability per ha

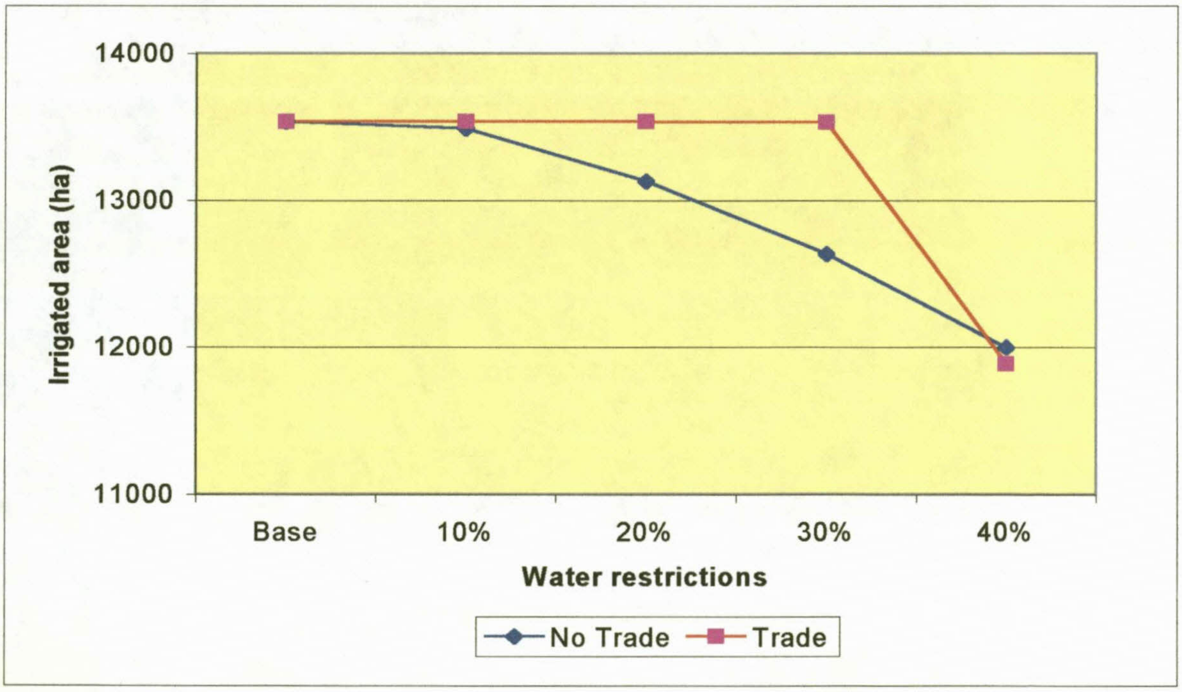

Figure 6.11: Irrigated area

The urban sector also gains through trade. Table 6.9 presents the water supply sources under no-trade and trade regimes. Trade clearly acts as a buffer against the increasing water scarcity. If it is not possible to trade water, consumption is generally lower.

Table 6.9: Urban water sources with and without trade (million m^3)

Item	**No trade**					**Trade**				
Scenario	Base	10%	20%	30%	40%	Base	10%	20%	30%	40%
Theewaterskloof Dam	125.0	112.5	100.0	87.5	75.0	123.0	112.5	100.0	87.5	75.0
Trade water	0.0	0.0	0.0	0.0	0.0	3.0	19.0	15.5	11.6	14.0
Other dams	185.0	166.5	148.0	129.5	111.0	184.0	166.5	148.0	129.5	111.0
Total urban usage	310.0	279.0	248.0	217.0	186.0	310.0	298.0	263.5	228.6	200.0

6.4.4 Changes in crop combinations through reallocation of water

The changes in crop combinations that occur with a 40 percent restriction are shown in Figure 6.12. It is clear that with water shortages less wine grapes and more table grapes are produced in the trade regime than without trade. Historically table grapes yield a higher financial return per m^3 than the other crops. Although this trend changed during the 1999/2000 season, the model assumes a longer-term view with regard to export prices. The table grape industry is reorganising itself at the moment and it is believed that these changes will have a positive impact on the export price of table grapes. During severe water scarcity the value of water and demand for it on the part of producers of high-value crops – e.g. table grapes – may thus rise to such levels that it pays some wine farmers to sell some or all of their water allotments to table grape farmers, who are willing to pay the high price in order to achieve a good crop. Thus in total less water will be used in viticulture, and more for table grapes, should water be tradable. This does not happen in the no-trade regime. The analysis does not show any drastic structural changes in the short run. This is not surprising because it is not possible to make structural changes in the short run. Some viticulturalists will in practice sell a major part of their water in a year with such severe restrictions and use the rest to keep the vines alive in the expectation of better times to come.

If the Upper-Berg model was a dynamic model (more than a one year planning horizon), the changes to perceived water restrictions in future could have been modelled and this would induce more structural changes. The analysis also pointed out that the profitability of double cropping with vegetables is often underestimated compared to long-term crops. The restriction scenarios did not induce any reduction in the area produced under vegetables. This can only be explained by the fact that the combination of vegetables is more profitable than wine grapes and some other fruits.

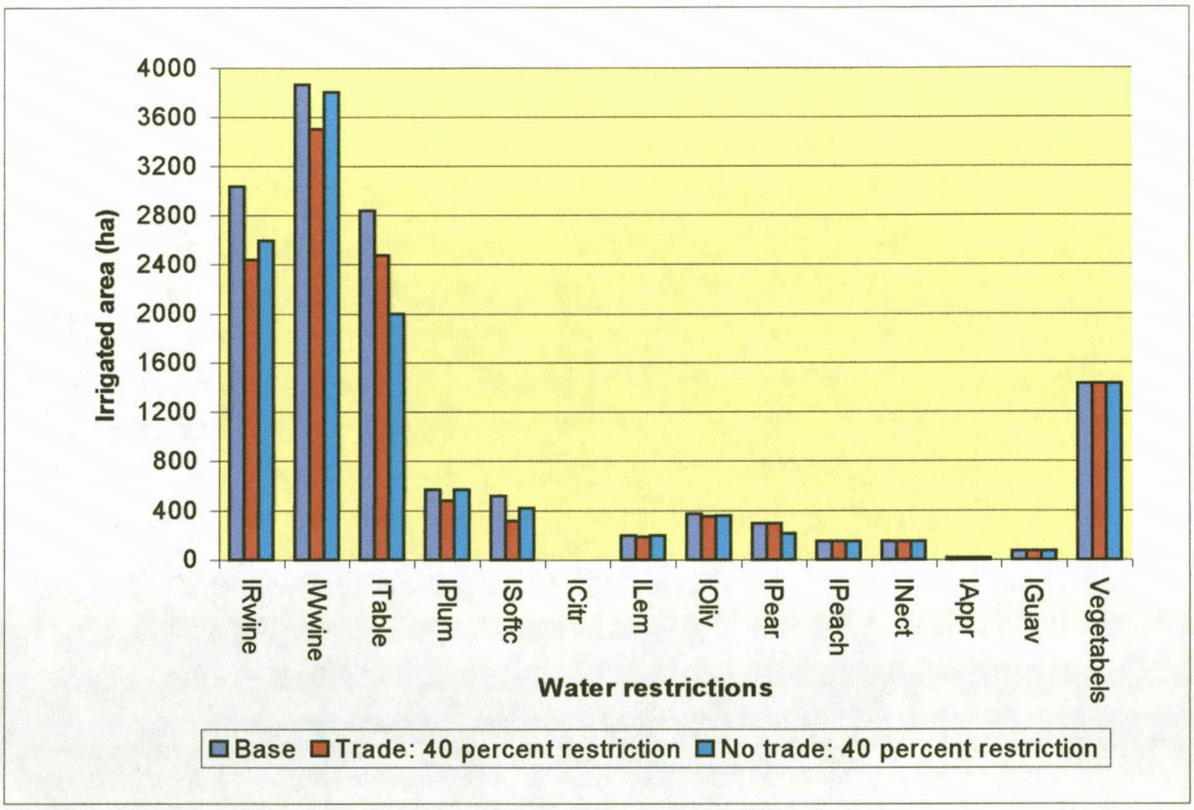

Figure 6.12: Crop combination with trade and without trade

6.4.5 Marginal value of water sources

Table 6.10 presents the marginal values of other existing and potential water sources with both trade and no-trade regimes. The development of a new source will be uneconomical for as long as the marginal cost of the source is greater than the marginal value of water. It is not possible in the short-run to build new infrastructure. However, the model calculates the marginal value of present supply sources as well as potential augmentation sources. In the no-trade regime the marginal values of potential sources are positive, except for desalination and recycling. This means that when water restrictions sets in, with no trade possible, the objective function will increase with the indicated value for every additional unit of the source. Desalination and recycling are very expensive and will only become an economic option if water restrictions of 20 percent in the case of recycling and 40 percent in the case of desalination become permanent features. With a trade regime however, all the potential sources have negative marginal values in the base scenario. This means that development of a new source will cause the total welfare of water users to decline. However, as soon as there is a 10 percent persistent restriction on water use, all the options, with the exception of desalination and recycling, become viable. Recycling only becomes an option with 30 percent and desalination at 40 percent restrictions. This indicates that water trading can reduce water inefficiencies and can allow water to flow to where it is needed. The value of all sources is initially lower in the trade than in the no-trade regime. However, as soon as scarcity sets in, the marginal value of the sources increase more rapidly in the with-trade scenarios.

Table 6.10: Marginal value of other and possible urban water sources (Rand/m^3)

Water source	**No trade scenarios**					**Trade scenarios**				
Other sources	**Base**	**10%**	**20%**	**30%**	**40%**	**Base**	**10%**	**20%**	**30%**	**40%**
Table Mountain dams	10.1	12.5	17.0	24.6	31.1	1.4	10.0	14.8	21.4	35.4
Steenbras Dam	10.1	12.5	17.0	24.6	31.1	1.4	10.0	14.8	21.4	35.4
Wemmershoek	10.1	12.5	17.0	24.6	31.1	1.4	10.0	14.8	21.4	35.4
Voëlvlei dam	9.7	12.1	16.5	24.2	30.6	0.9	9.5	14.3	20.9	35.0
Palmiet	8.7	11.1	15.6	23.2	29.7	0.0	8.6	13.4	20.0	34.0
Aquafers	10.1	12.5	17.0	24.6	31.1	1.4	10.0	14.8	21.4	35.4
Theewaters	10.1	12.5	17.0	24.6	31.1	0.0	0.0	0.0	0.0	0.0
Average value	8.4	10.5	14.3	20.9	26.4	0.9	8.3	12.4	18.1	30.1
Possible sources										
Skuifraam dam	6.7	9.1	13.6	21.2	27.7	-2.0	6.6	11.4	18.0	32.0
Lower Hangklip	6.4	8.8	13.2	20.9	27.3	-2.3	6.3	11.0	17.7	31.7
Campanula	5.4	7.8	12.2	19.9	26.3	-3.4	5.2	10.0	16.6	30.7
Voëlvlei/Lorelei	3.7	6.1	10.5	18.2	24.6	-5.1	3.5	8.3	14.9	29.0
Molenaars	7.5	9.9	14.3	22.0	28.4	-1.3	7.3	12.1	18.7	32.8
Lourensrivier	7.6	10.0	14.4	22.1	28.5	-1.1	7.5	12.2	18.9	32.9
Cape flats aquifer	7.0	9.5	13.9	21.6	28.0	-1.7	6.9	11.7	18.3	32.4
Desalination	-18.4	-16.0	-11.6	-3.9	2.5	-27.2	-18.6	-13.8	-7.2	6.9
Recycling	-4.8	-2.4	2.0	9.7	16.1	-13.6	-5.0	-0.2	6.4	20.5

The market mechanism ensures that the value of water reflects its true scarcity value. In the no-trade regime this scarcity is hidden through the fact that inefficiencies (misallocation) still exist in the system. The results are consistent with those of many other authors (Thobani, 1995; Easter and Hearne, 1995; Young, 1986; Anderson, 1982, 1983 and 1985; Colby, 1990; Eigenraam and Stoneham, 1997; Brennen and Scoccimarro, 1999; Tisdell, 1996)

6.4.6 Trade flows

It will be long-winded to show trade flows for every scenario because of the many possible combinations. Neither is it necessary, as the benefits of trade in terms of efficiency have already been illustrated. It is however advisable to gain some insight, and for this purpose only the base scenario with trade is discussed. A close relationship exists between NDI per typical farm and the trade that takes place when trade is permitted. NDI is however not the only criterion when a water market is introduced (in the absence of critical shortages), users will first trade their unused water rights before considering to scale down their present consumption. In order to understand the trade flow it is necessary to consider Table 6.11, which presents typical farms with surplus water and those with water shortages.

Table 6.11: Agricultural supply and usage (000' m^3)

Region	Allocation	Dam capacity	Winter water	Total supply	Usage	Surplus
Berg1.1	352	111	236	699	620	79
Berg1.2	305	46	187	538	506	33
Berg1.3	189	181	135	505	487	18
Berg1.4	1493	385	1341	3219	2720	499
Berg1.5	1416	208	839	2462	2286	176
Berg1.6	2867	3332	3021	9220	6488	2732
Berg2.1	2260	361	1149	3771	3804	-33
Berg2.2	3612	872	1565	6049	6229	-181
Berg2.3	8127	1510	5048	14685	13644	1041
Berg3.1	1193	-	509	1702	1289	413
Berg3.2	1064	-	409	1474	1114	359
Berg3.3	4590	-	2995	7585	5608	1977
Berg3.4	1766	266	787	2819	2057	762
SAP.1	1017	839	-	1855	2860	-1005
SAP.2	417	332	-	749	1250	-501
NAP.1	4361	1541	-	5902	6410	-508
PB.1	3963	2720	-	6683	9123	-2440
RK.1	395	422	542	1360	965	395
RK.2	429	932	577	1939	1510	429
RK.3	2049	1960	2583	6592	4543	2049
Total	**41863**	**16019**	**21923**	**79806**	**73511**	**6294**

This trade flow between the regions is presented in Table 6.13. According to Tables 6.11 and 6.13 no trade to the urban sector will occur before the "internal" agricultural demand is satisfied. The total in the "Surplus" column in Table 6.11 is the net surplus of water after all shortages have been eliminated within agriculture which, according to Table 6.11, is the exact amount of water being traded to the urban sector. In the base analysis it was pointed out that the fixed component of the transaction costs is twice as high for transfer between agriculture and urban usage as for internal agricultural trading to consider the social welfare aspects of agricultural to urban water transfers. This is the main reason why demand requirements are first satisfied within the agricultural sector and points out that transaction costs can be used as a policy measure to prevent unwanted transfers. The impact of transaction cost is discussed in the next chapter. All surplus water will be traded until the market is in equilibrium, the market must be cleared. Easter *et al* (1997) came to similar conclusions. Table 6.11 shows that the typical farms in the Berg1 region do not use their full water allotment for the season. The typical farms in Berg1 will therefore trade their water to both the urban sector, other farmers in the Berg1 region and to typical farms in almost all the other regions. Temporary trade within the model is to a great extent seasonal. The surplus calculated in Table 6.11 can therefore be misleading if the seasonal usage is not considered. To illustrate the point consider the seasonal usage for the typical farm Berg1.1 in Table 6.12.

Table 6.12: Seasonal usage for the Berg1.1 typology ('000 m^3)

Month	Usage	Summer	Winter
January	92	92	-
February	84	84	-
March	70	70	-
April	59	-	59
May	9	-	9
June	3	-	3
July	4	-	4
August	7	-	7
September	50	-	50
October	67	67	-
November	83	83	-
December	93	93	-
Total	**620**	**489**	**131**

Although irrigation boards request the DWAF to release a certain volume of water every month from the Theewaterskloof Dam they can withdraw their summer allocation only from October to March. If the irrigation water use for a typical farm with a specific crop combination exceeds supply during a certain period, this typical farm may buy water even though the annual allocation seems to be adequate. Berg1.1 is a typical example. Consider Table 6.12. The annual demand is 620 000 m^3 but the summer allocation (peak demand) is only 489 000 m^3. The annual allocation is therefore misleading from a supply point of view.

Table 6.13: Trade flows with a potential water market: Base scenario

Traded from typology	Volume traded 000' m^3	Traded to typology	Month
Berg1.1	105	URB.1	Febr
Berg1.2	87	URB.1	Nov
Berg1.3	18	PB.1	Nov
Berg1.4	936	URB.1	Sept
Berg1.5	97	URB.1	May
Berg1.5	24	Berg1.2	Nov
Berg1.5	424	URB.1	Sept
Berg1.6	999	URB.1	Aug
Berg1.6	181	Berg2.2	Dec
Berg1.6	137	PB.1	Dec
Berg1.6	348	Berg1.4	Febr
Berg1.6	310	NAP.1	Febr
Berg1.6	463	PB.1	Febr
Berg1.6	26	Berg1.1	Oct
Berg1.6	269	SAP.1	Oct
Total from Berg1	**4422**	-	-
Berg2.1	360	Berg1.5	Febr
Berg2.1	98	URB.1	July
Berg2.3	3	SAP.2	Nov
Berg2.3	2357	URB.1	Febr
Total from Berg2	**2819**	-	-
Berg3.1	413	PB.1	Febr
Berg3.2	260	SAP.1	Nov
Berg3.2	100	PB.1	Jan
Berg3.3	89	Berg1.4	Jan
Berg3.3	9	Berg1.5	Oct
Berg3.3	1320	Berg2.3	Jan
Berg3.3	400	SAP.1	Jan
Berg3.3	76	SAP.1	Febr
Berg3.3	84	SAP.2	Oct
Berg3.4	762	URB.1	April
Total from Berg3	**3512**	-	-
RK.1	198	SAP.2	Febr
RK.1	197	NAP.1	Febr
RK.2	429	URB.1	March
RK.3	31	Berg1.2	March
RK.3	492	Berg2.1	Jan
RK.3	217	SAP.2	Dec
RK.3	1310	PB.1	Nov
Total from RK	**2873**	-	-
Total trade			**13625**
Total urban			**6294**
Total agriculture			**7331**

Bergl.1 predominantly grows summer crops with a high summer water requirement. According to Table 6.12, Bergl.1 has an annual surplus of 79 000 m^3 of water. Even although this is true on an annual basis it is necessary for Bergl.1 to buy water during October to be able to satisfy the October demand for water. On the other hand, the typical farm has a surplus of 105 000 m^3 of water during February to trade to the urban sector. The example shows that water trade makes irrigation water management more flexible and leads to gains in efficiency. If the urban sector could not buy water in February from Bergl.1 it would be necessary to develop expensive new water sources to bridge this month and even worse, they would have a surplus of urban water (at a very high cost) during other times of the year.

The general trend in Table 6.13 is for farms with a relatively low NDI per m^3 to trade water to farms with a relative high NDI per m^3. The farms with the highest NDI per m^3 are SAP1, SAP2, and PB1. These farms are all water buyers in the model. On the other hand, the farms with the lowest NDI per m^3 (Bergl.3, Bergl.2, RK1 and RK3) all sell water. However as pointed out earlier in this section, the NDI per m^3 is not the only criterion that indicates where water will flow. The analysis in Table 6.13 points out that the effect of seasonal demand is probably much higher in the event of relatively low scarcity than NDI per m^3. The analysis also emphasises the importance of winter water trade to the urban sector if the infrastructure should exist. It is clear from Table 6.13 that the majority of trade volumes to the urban sector in the base scenario are winter water from the agricultural sector.

6.5 Urban water use growth scenarios

The results of the urban growth scenarios are presented in Figure 6.18 to 6.24. The detailed results can be found in Appendix C (Tables C.5 to C.8). The implications of this scenario correspond with water restrictions. However, there are two major differences. The first is that a growth in the urban demand for water means a shift in the demand curve to the right (unlike the previous scenario) due to population growth or a per capita increase in water use, or both. The second is that it is a long-run scenario; farmers can change their crop combinations more easily over the long run and the urban sector can build new water infrastructure if necessary.

The scenarios are discussed in terms of the welfare implications for the urban as well as the agricultural sector.

6.5.1 Objective function parameters

The increase in the objective function stems from increases in water sales by the urban water utility (see Figure 6.13).

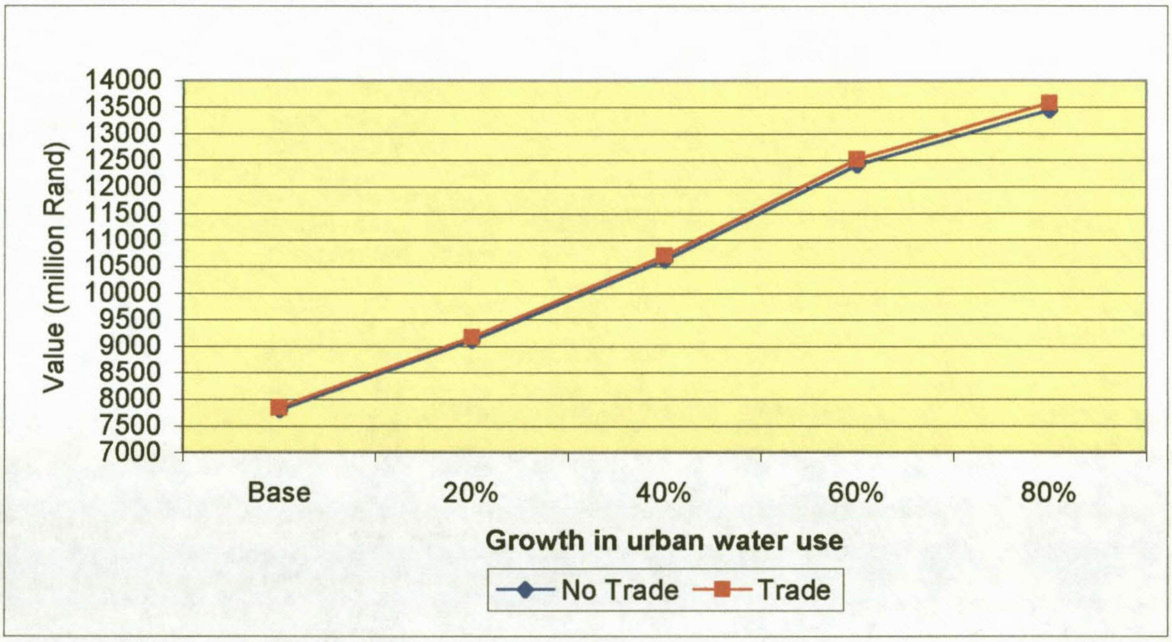

Figure 6.13: Objective function value – urban demand growth scenarios

Figure 6.13 reveals that there is not much of a difference in the objective function value between the trade and no-trade scenario. There appears to be a slight but probably insignificant increase in difference between the scenarios after a 60 percent increase in water-use growth.

6.5.2 Agricultural water demand

Figure 6.14 presents the changes in irrigation intensity. Farmers can only adapt to a certain point. After this point the opportunity costs become too high to keep the water and water sales to the urban sector increase rapidly.

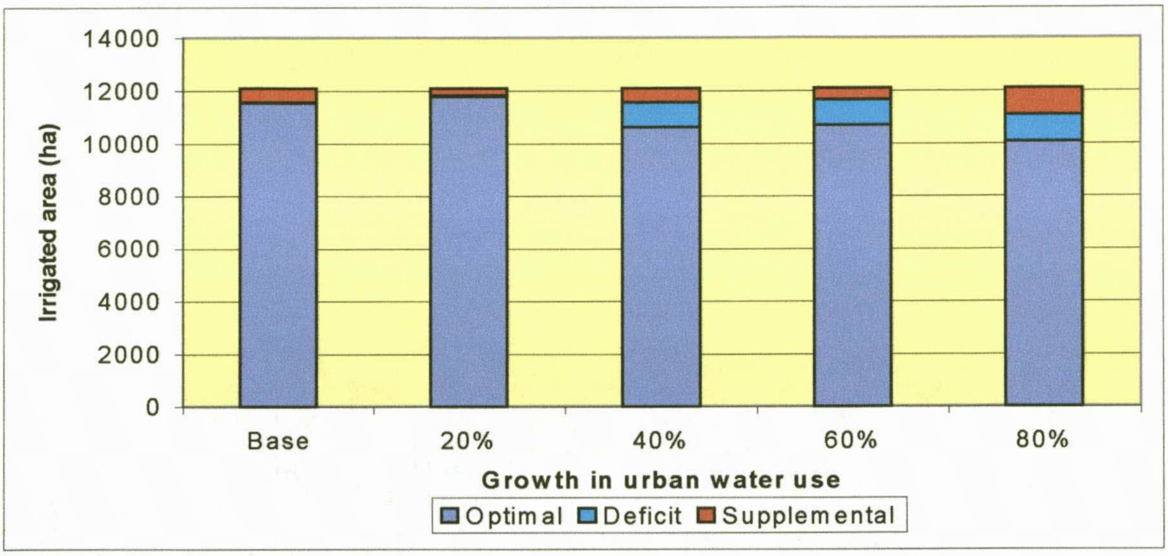

Figure 6.14: Change in irrigation intensity under trade scenarios (ha)

Figure 6.15 presents the marginal value of irrigation land. In the initial impact, land values increase. This can be explained by Figure 6.14, which shows that farmers' first reaction is to produce a larger area under optimal irrigation (higher value). During the farm survey one question asked was what farmers would do if they could attain more water through trade? More than 80 percent of the farmers' response was that they would increase their irrigation intensity before thinking of expanding their farming operations. It is clear that after the initial increase there is a rapid decline in the marginal value of land as farmers change to supplemental and deficit irrigation.

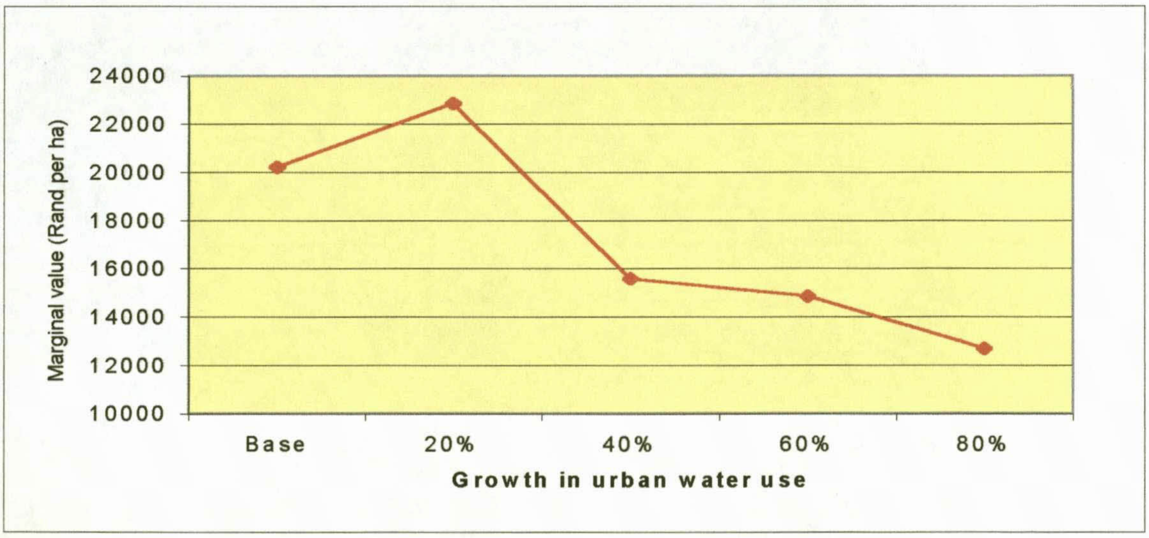

Figure 6.15: Marginal value of irrigation land (R/ha)

Figure 6.16 shows the decline in agricultural water usage as water sales to the urban sector increase. The initial reaction (20 percent increase in urban demand) confirms the conclusion made from Figure 6.14, i.e. farmers change from a lower-value to a higher-value use for water before selling water to the urban sector.

When urban growth increases by 40 percent the opportunity cost to keep this water becomes too high and farmers sell more water to the urban sector

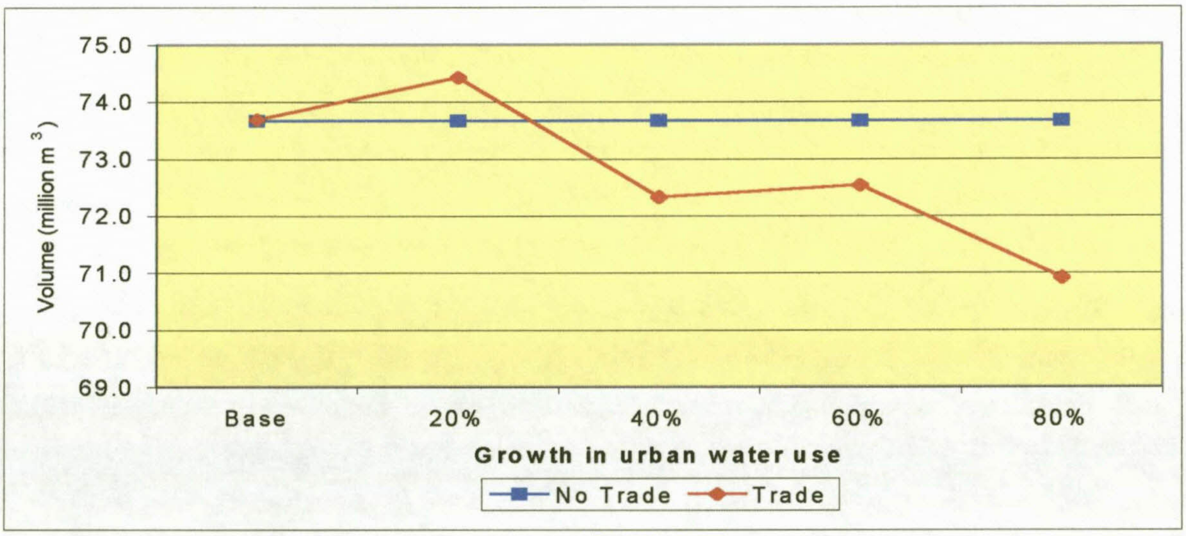

Figure 6.16: Agricultural water consumption (million m^3)

6.5.3 Urban water supply and demand

Table 6.14 shows that as with water restrictions, a water market acts as a buffer when scarcity sets in; however, water markets can only alleviate the problem of growing water demand, not solve it. The major advantage of water markets is that it delays investment in expensive new capital-intensive water schemes such as the Skuifraam through efficiency gains and natural reallocation.

Table 6.14: Urban water supply with growth in water use (million m^3)

Item	**No trade**					**Trade**				
Scenario	**Base**	**20%**	**40%**	**60%**	**80%**	**Base**	**20%**	**40%**	**60%**	**80%**
Theewaterskloof Dam	93.0	93.0	93.0	93.0	93.0	93.0	93.0	93.0	93.0	93.0
Trade	0.0	0.0	0.0	0.0	0.0	37.8	40.7	42.0	42.0	43.6
Other dams	185.0	185.0	185.0	185.0	185.0	179.2	185.0	185.0	185.0	185.0
Possible sources	32.0	94.0	168.4	257.7	311.3	0.0	53.3	126.4	215.7	267.7
Total urban water supply	310.0	372.0	446.4	535.7	589.3	310.0	372.0	446.4	535.7	589.3

6.5.4 Marginal value of water

Figure 6.17 shows the increase in the marginal value of water at different urban water demand growth scenarios. When no trade is permitted the agricultural value of water stays exactly the same because it is not tradable and has only an agricultural value. However, without trade the value of water to the urban sector continues to rise because of the growth in urban water use and the high capital cost of developing new sources.

Introduction of a market subjects agricultural water to market forces and it becomes more valuable due to both its tradability and the fact that new water sources for the urban sector are very expensive to develop. In the agricultural sector the value of the existing water right is higher before trade than when trade starts. The reason for this can be found in the inefficiencies ("artificial scarcity") that exist in the allocation system before trade. As soon as it is possible to trade a "new" source, trade water is available and the value of the existing entitlement is lower until trade water becomes scarce. It is significant to note that even at high values for water the agricultural sector does not sell all their water rights to the urban sector.

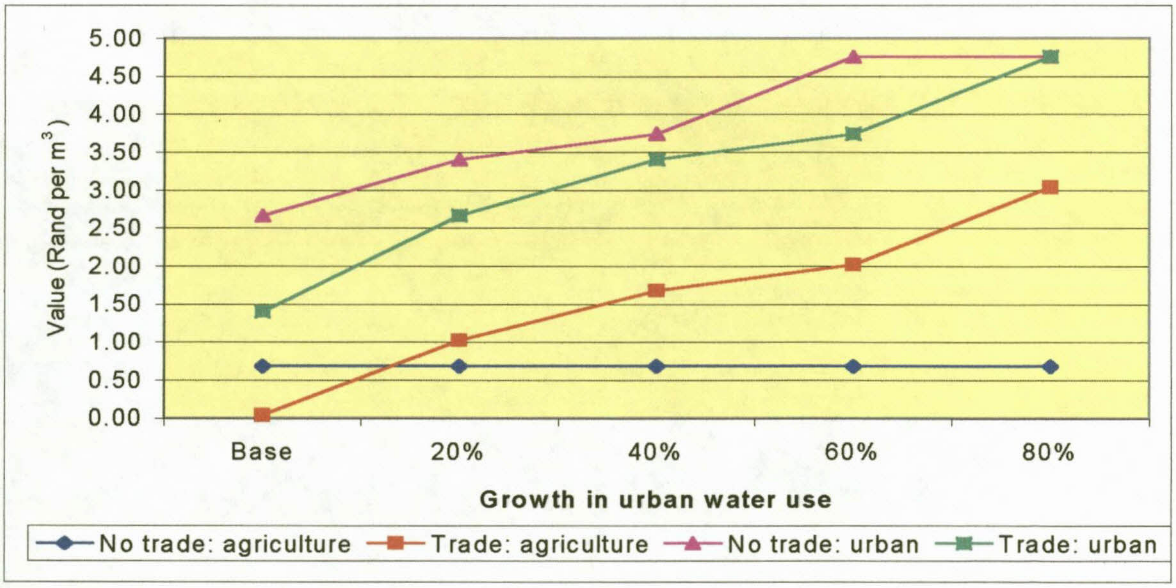

Figure 6.17: Marginal value of water (million m^3)

Market transactions are precipitated by differences in the value of water in alternative uses and at different locations. These differences must be large enough to outweigh the costs of obtaining water through the market process; water markets will therefore become active only where and when water is sufficiently scarce, and hence valuable. Conversely, water markets are unlikely to become active where many water rights remain unappropriated, where water supply investments continue to be favoured over reallocation, where transportation and transaction costs are very high, or where there are other sources of low-cost water (Colby, 1988).

Table 6.15 presents the value of water supplies to the urban sector. As soon as a water market is introduced the value of other water supply sources declines because the urban sector can secure additional supplies more cheaply through trading. However, as water becomes increasingly scarce due to urban growth, trade will eventually cause the value of other supply sources to increase to the same levels as when trade is not permitted.

Table 6.15: Marginal value of urban water supplies (R/m^3)

	No-trade scenarios					Trade scenarios				
Other sources	**Base**	**2005**	**2010**	**2015**	**2020**	**Base**	**2005**	**2010**	**2015**	**2020**
Table Mountain dams	2.7	3.4	3.7	4.8	4.8	1.4	2.7	3.4	3.7	4.8
Steenbras Dam	2.7	3.4	3.7	4.8	4.8	1.4	2.7	3.4	3.7	4.8
Wemmershoek	2.7	3.4	3.7	4.8	4.8	1.4	2.7	3.4	3.7	4.8
Voëlvlei Dam	2.2	2.9	3.3	4.3	4.3	0.9	2.2	2.9	3.3	4.3
Palmiet River	1.3	2.0	2.3	3.4	3.4	0.0	1.3	2.0	2.3	3.4
Aquafers	2.7	3.4	3.7	4.8	4.8	1.4	2.7	3.4	3.7	4.8
Theewaters	2.7	3.4	3.7	4.8	4.8	1.4	2.7	3.4	3.7	4.8
Average value	**2.0**	**2.6**	**2.9**	**3.8**	**3.8**	**0.9**	**2.0**	**2.6**	**2.9**	**3.8**
New sources (opportunity cost)										
Skuifraam Dam	-0.7	0.0	0.3	1.4	1.4	-2.0	-0.7	0.0	0.3	1.4
Lower Hangklip	-1.1	-0.3	0.0	1.0	1.0	-2.3	-1.1	-0.3	0.0	1.0
Campanula	-2.1	-1.4	-1.0	0.0	0.0	-3.4	-2.1	-1.4	-1.0	0.0
Voëlvlei/Lorelei	-3.8	-3.1	-2.7	-1.7	-1.7	-5.1	-3.8	-3.1	-2.7	-1.7
Molenaars River	0.0	0.7	1.1	2.1	2.1	-1.3	0.0	0.7	1.1	2.1
Lourens Rivier	0.1	0.9	1.2	2.2	2.2	-1.1	0.1	0.9	1.2	2.2
Cape flats aquifer	-0.4	0.3	0.7	1.7	1.7	-1.7	-0.4	0.3	0.7	1.7
Desalination	-25.9	-25.2	-24.8	-23.8	-23.8	-27.2	-25.9	-25.2	-24.8	-23.8
Recycling	-12.3	-11.6	-11.2	-10.2	-10.2	-13.6	-12.3	-11.6	-11.2	-10.2

The model can also be used to determine optimum times for the completion of new water works – as done in Table 6.16. In the no-trade scenarios the Moolenaars River and Lourens River augmentation schemes should already have been built to prevent water restrictions. Also, if trade is not possible it is already necessary to have the Skuifraam Dam ready to deliver water in 2005: should a water market be introduced, the Moolenaars and Lourens

River schemes become necessary only in 2005 and the Skuifraam Dam in 2010. As is the case with water restriction, a water market will provide a buffer against the increasing demand for urban water. Except for the buffer effect of trade the postponement of high capital expenses can have important positive welfare implications for the economy of the Western Cape province.

Table 6.16: Volume of water from other sources (million m^3)

Source	No-trade scenarios					Trade scenarios				
Use of other sources	**Base**	**2005**	**2010**	**2015**	**2020**	**Base**	**2005**	**2010**	**2015**	**2020**
Table Mountain dams	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Steenbras Dam	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0
Wemmershoek Dam	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0
Voëlvlei Dam	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0
Palmiet River	31.0	31.0	31.0	31.0	31.0	25.2	31.0	31.0	31.0	31.0
Aquifers	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Theewaterskloof Dam	141.2	141.2	141.2	141.2	141.2	165.0	167.8	167.8	167.8	167.8
New source development										
Skuifraam Dam	0	19	73	73	73	0	0	51	73	73
Lower Hangklip	0	0	20	100	100	0	0	0	68	100
Campanula	0	0	0	10	63	0	0	0	0	20
Voëlvlei/Lorelei	0	0	0	0	0	0	0	0	0	0
Molenaars River	12	37	37	37	37	0	33	37	37	37
Lourens River	20	20	20	20	20	0	20	20	20	20
Cape flats aquifer	0	18	18	18	18	0	0	18	18	18
Desalination	0	0	0	0	0	0	0	0	0	0
Recycling	0	0	0	0	0	0	0	0	0	0

6.6 Conclusion

This chapter showed how water markets could induce more efficient use of water. Trade takes place from water users with surplus water rights or water that they cannot use beneficially, to users with inadequate water supplies, who attach a higher value to the water. This gain in efficiency is manifested in the marginal value of water. When the market is in equilibrium all water users attach the same value to water and the marginal value of water is lower than with the no-trade regime.

It was also pointed out that although the model provides for the permanent trade of water rights, the model indicates only temporary trade. The reason for this is that the model is static. In a static model the model can differentiate between the two types of trade only if the transaction costs differ. The permanent trade options were however included to provide for future development of a dynamic model.

This chapter also showed that water markets can act as a mechanism to facilitate a fair reallocation of water on a willing seller, willing buyer basis. Market transactions are *fair* in the sense that water reallocation takes place through voluntary mutually beneficial trades with perceived advantages for all the parties involved; each party must be made better off or one would refrain from trading. Markets can however guarantee fairness only if no single market participant can affect market prices. In addition, unless conducted in an institutional framework, which causes market participants to take into account third-party impacts, markets generally cannot guarantee fairness to third parties who may be negatively affected by market transactions.

Finally, although nonmarket institutions can theoretically serve some goals for water allocation, such as predictability, equity and fairness, and the need to reflect collective, public or social values, the existence of these problems "does not necessary call for a nonmarket alternative" (Anderson, 1982), because "market failure" in some abstract sense does not mean that a nonmarket alternative will not also fail in the same or in some other abstract sense (Castle, 1965). The relevant comparison is thus one between imperfect market solutions and imperfect administrative or political solutions, not between imperfect market solutions and the mirage of idealised administrative solutions.

Chapter 7

THE IMPACT OF TRANSACTION COSTS ON WATER TRADE

7.1 Introduction

One of the principal benefits of water markets is the almost unlimited possibility for water reallocation with the only real restraint being the ingenuity of the trading parties. Water rights transfers can take a variety of forms, each serving a different operational purpose in a water resource system (Israel and Lund, 1995). The choice of the form of water transfer depends on the structure of the market, the legal and third party considerations that the transaction must accommodate, the definition and characteristics of the water right, the transaction costs, the characteristics of supply and demand, other local conditions, and, above all, the needs of the parties to the transaction.

The permanent transfer of title, including all benefits, costs, risks and obligations associated with the right is usually a response to long-term changes in demand and supply conditions, which increase the marginal value of water in some uses and decrease it in others. Sales are the preferred market structure when the goal is to satisfy permanent demand shifts (Howitt, 1994). The permanent transfer of water rights through sales can be expected to be less frequent than lease contracts. Sales are common in intersectoral transfers, with irrigated agriculture being the dominant water seller and urban users the principal buyers.

The leasing of water rights involves the sale of water, but not of the water right. Under a lease, the title to the water right remains with the lessor and at the end of the contract, the right must be returned. Leases are a preferred market response to short-term changes in demand and supply conditions. These operations are commonly referred to as the spot market for water. Water users may find it advantageous to engage in lease contracts for a variety of reasons. The lessor has an opportunity to earn revenue in the temporary trade of surplus water rights while not giving up these water rights. Leases are particularly useful when users need to accommodate:

- a short-term demand for additional water;
- a long-term but variable demand;
- any use that has a predictable and fixed lifespan;
- a use of uncertain duration, e.g. a farmer facing variable commodity prices;
- highly variable supplies, e.g. where it is not economical to transport water in periods of sufficient water supply;
- water users' unwillingness or inability to commit the resources necessary to buy the water rights or the desire to limit their ownership of water rights; and
- unexpected events (Saliba and Bush, 1987).

Rosegrant and Gazmuri (1994) pointed out that transaction costs arise in water allocation whether water is allocated through administrative control or through the market process, and include:

- the cost of identifying profitable opportunities for transferring water;
- the cost of negotiating or administratively deciding on the water transfer;
- the cost of monitoring third-party effects and other externalities;
- the infrastructure cost of conveying the water and monitoring the transfer;
- the infrastructure and institutional cost of monitoring, mitigating or eliminating third-party effects and externalities.

It was indicated in Chapter 2 that the costs involved in the transfer of property, or transaction costs, and the costs of transporting water, can significantly affect the capacity of any market to operate efficiently. If water marketing is to achieve its full potential, markets must be designed to minimise these costs. Water marketing may however, lead to efficiency gains, even if transaction and transportation costs are high. Moreover, increasing water scarcity raises gains from trade relative to these costs. Transaction and transportation costs can be lowered by technological advance and institutional investment and are also likely to fall somewhat as the level of trading increases, as there are often strong learning by doing effects. This chapter explores the effect of transaction costs on trade within a water market policy regime. The possibility of using transaction costs as policy measure to attain certain objectives will also be tested. The following section describes the transaction costs used in the scenarios and gives an outlay of the scenarios to be tested. The results of the different scenarios follow thereafter. The last section presents a summary of the most important conclusions with regard to the impact of transaction costs.

7.2 Transaction costs scenarios

There is no example of a relatively free water market in South Africa and thus of the transaction costs that will apply in such a market. It was therefore assumed that for a high transaction cost scenario the transaction cost for permanently traded water would at least not be higher than the cost incurred during the old water law regime. In the Orange River, where water transfers were common since the late 1980s, the cost varied between R2 000 and R6 000 per farm of 30 ha with an allocation of 15 000 m^3 per ha. According to Armitage (1999) this cost did not provide for electricity, other irrigation infrastructure and brokers' fees. Although there are no published transaction cost figures available for the Berg River, the farm survey revealed that farmers paid about 6 cent per m^3 of water for permanent water transfers. Informal temporary water transfers between farmers are common in the Berg River. According to the survey results there have been no direct transaction costs as most of the transfers have been "friendly" agreements between farmers.

According to Hearne and Easter (1997), the degree to which transaction costs are caught up in the judicial system in the United States of America varies between states, as do transaction costs, which have been estimated to range between 2 and 20 percent of the value of water. It has been shown by Garrido (1998) in Spain that if the transaction costs exceed 8-12 percent of the market price, trading and the gains from trading would be to small to justify the expense of establishing formal water markets. In the absence of empirical data, it was decided to accept a relatively low transaction cost for both permanent and temporary trade. The variable transaction cost for permanent and temporary water transfers was assumed to be 10 percent and 4 percent respectively of the value of water in the base analysis (PMPOPT). The fixed transaction costs assumed are pure speculation, as no evidence exists in South Africa or in international literature to suggest what this will be. The costs shown in parentheses below are 20-year present value costs; the present value of the base cost was discounted at 13 percent over a 20-year period. The following transaction costs were accepted for the base trade analysis:

- A variable temporary trade transaction cost of 6.3 cents (11 cents) per m^3 of water. This amounts to approximately R315 per ha of an entitlement of 5 000 m^3.
- A fixed temporary trade transaction cost of R576 (R1 000) per transaction for trade within irrigation regions.
- A fixed temporary trade transaction cost of R2 880 (R5 000) per transaction for trade from irrigation regions to the urban sector.
- A variable permanent trade transaction cost of 12.1 cents (21 cents) per m^3 of water. This amounts to approximately R605 per ha with an entitlement of 5 000 m^3. When the transaction cost is related to the value of water in the base analysis without trade (PMPOPT) it comprises about 10 percent of the value of water.
- A fixed permanent trade transaction cost of R2 880 (R5 000) per transaction for trade within irrigation regions.
- A fixed permanent trade transaction cost of R5 760 (R10 000) per transaction for trade from irrigation regions to the urban sector.

The higher fixed transaction cost for transfers from agriculture to urban areas was chosen in order to provide for the possible social welfare impact of agricultural to urban water transfers (see Chapter 2). In South Africa policies are directed at affordable water for the poor but it is quite possible that exactly the opposite may happen. There is evidence (Eckert *et al*, 1997) that agriculture in the Western Cape has considerable multiplier effects and it may prove to be sounder and economically more rational to protect agriculture through trade barriers such as transaction costs. The assumptions with regard to transaction costs in this study have been made solely for illustrative purposes. In order to create an environment for trade a base analysis with the following characteristics was constructed:

- The base urban demand for water was increased with 20 percent.
- The irrigation land was increased by 10 percent in the upper reaches of the river and 25 percent in the lower reaches of the river to provide for the possibility of expansion in irrigated agriculture.
- The agricultural entitlement to water was increased to 75 million m^3 water from the Theewaterskloof Dam and the urban entitlement decreased to 93 million m^3.

In the first round of analysis the transaction costs were increased in increments of 10 percent up to a 100 percent increase from the base costs.

7.3 Results

The detailed results of the transaction cost scenarios can be found in Appendix D (Table D.1 to Table D.4). In the first round of analysis, only small changes took place in the volume of trade as transaction costs increased. It was then decided to run the model with relatively large incremental increases to establish the point at which trade becomes sensitive to transaction costs. The following transaction cost scenarios were tested:

- Zero transaction costs
- 60 percent of the base transaction cost described in Section 7.2
- Base transaction costs described in Section 7.2
- 5 times the base transaction cost
- 5.6 times the base transaction cost
- 5.8 times the base transaction cost
- 6.2 times the base transaction cost

The transaction costs corresponding to the incremental changes are summarised in Table 7.1. The base transaction costs are those described in Section 7.2.

Table 7.1: Transaction cost scenarios (Rand per m^3)

Item	**x the base transaction costs**						
	0.0	**0.6**	**1.0**	**5.0**	**5.6**	**5.8**	**6.2**
Temporary trade variable TRC	-	0.04	0.06	0.32	0.35	0.37	0.39
Permanent trade variable TRC	-	0.07	0.12	0.60	0.68	0.7	0.75
Fixed temporary trade TRC: Agriculture	-	346	576	2881	3226	3342	3572
Fixed temporary trade TRC: Agriculture-Urban	-	1728	2881	14404	16132	16708	17861
Fixed permanent trade TRC: Agriculture	-	1728	2881	14404	16132	16708	17861
Fixed permanent TRC: Agriculture-Urban	-	3457	5762	28808	32265	33417	35722

TRC = transaction costs

The results of the transaction cost scenarios are discussed in three sections, in which the objective function parameters, market efficiency and the impact of transaction costs on water values are consecutively dealt with.

7.3.1 Objective function parameters

Figure 7.1 presents the changes in the value of the objective function with increases in transaction costs. There is only a slight decrease as transaction cost increase in the ranges of 60 to 100 percent of the base transaction costs. Increases to 5 times the base costs (32 cents) cause the real impact of transaction costs to become evident. The advantages of trade are also gradually eroded with increases in the transaction costs.

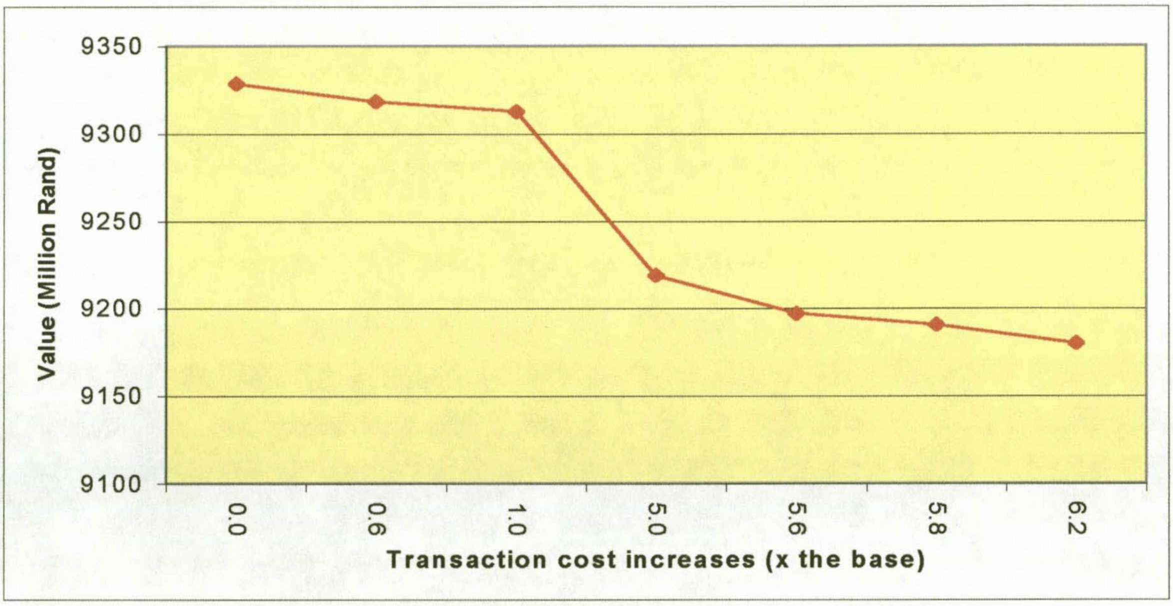

Figure 7.1: Objective function (million Rand)

The results indicate that the base transaction costs as calculated in Section 7.2 are too low to have a real impact. Transaction cost only shows a significant impact with variable transaction costs much higher than 6 cent per m^3 (the base transaction cost) of variable temporary transfer transaction cost. The 6 cents per m^3 of water represents approximately 4.3 percent of the value of an urban water right in the base analysis (PMPTR1) with trade. The results are therefore in accordance with that of Garrido (1998) who found that if transaction cost exceeds 8-12 percent of the value of the transaction, trade is prohibited.

Figure 7.2 presents the total NDI. When the impact on NDI is considered it should be kept in mind that the transaction cost in the model is lower for trade between irrigators than for trade to the urban sector. There is an initial decline in the NDI between the zero transaction costs and 60 percent of the base increase in transaction costs. After this the NDI stabilises up to

100 percent of the base transaction cost and then declines rapidly as transaction costs move to a level 5 times higher. It thereafter increases slightly to decrease slightly again after the 5.8 level.

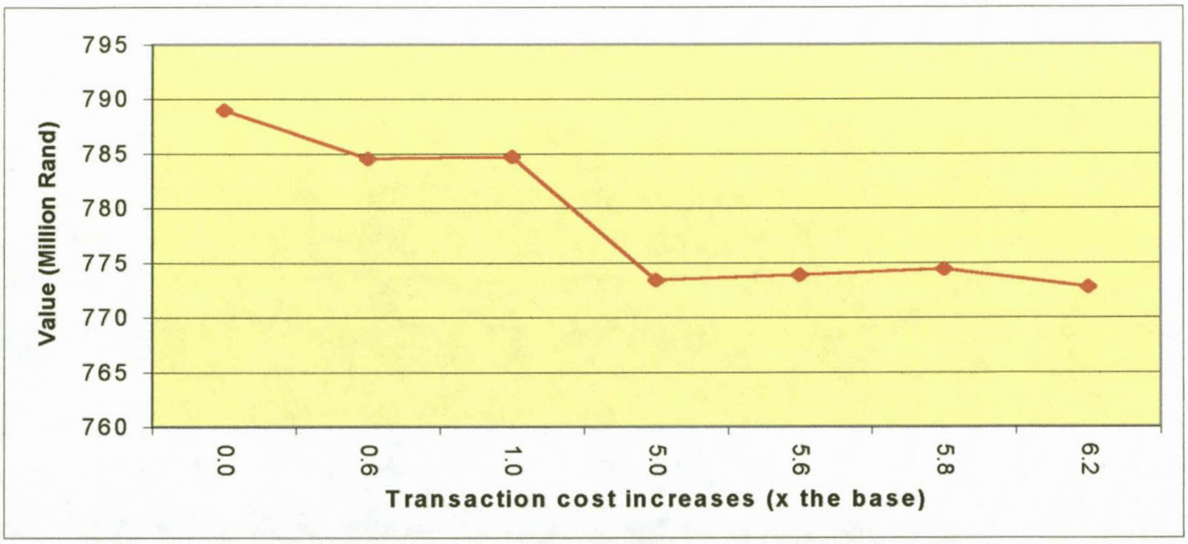

Figure 7.2: Total NDI with increasing transaction cost (million Rand)

The reaction of the agricultural sector to increasing transaction costs is explained in Figure 7.3. When transaction costs increase to 5 times that of the base costs, transaction costs erode the advantages of trade between the agricultural sector and the urban sector. Figure 7.3 indicates the reason why the NDI stabilises and even increases to some extent. As trade to the urban sector decreases, trade within the agricultural sector increases to some extent.

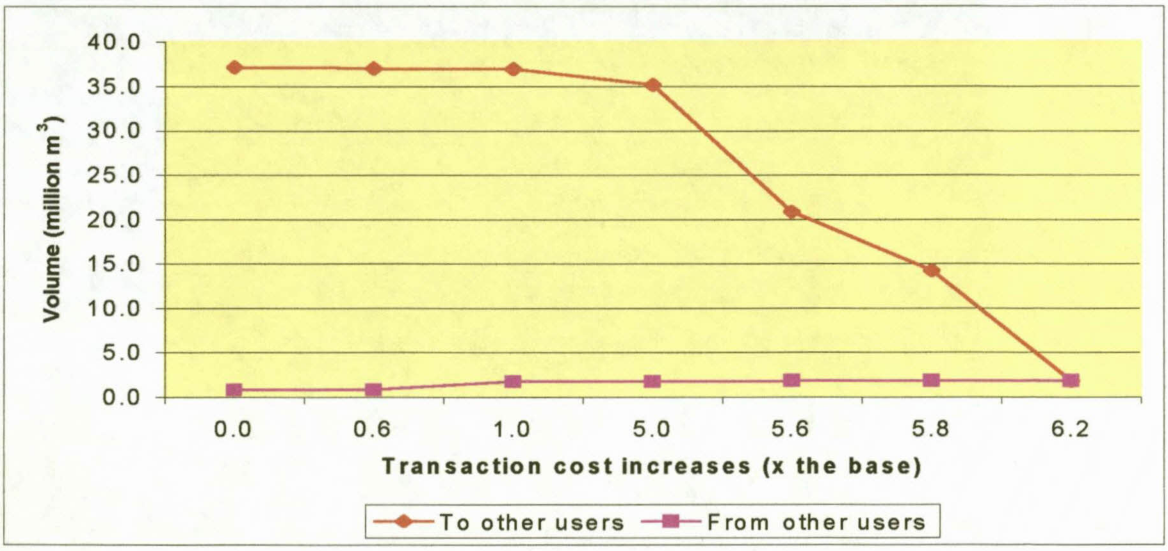

Figure 7.3: Agricultural water trade (million m^3)

If the trade volume to the urban sector is reduced through a disincentive to trade, there is more water available within the agricultural sector; farmers increase their irrigation intensity (produce higher value crops) and the NDI increases. However, this is only up to a point where the transaction costs increase to 5.8 times that of the base. After this the NDI starts to decrease again as the transaction costs within the agricultural sector also become too high for beneficial use of traded water.

7.3.2 Transaction costs and market efficiency

Figure 7.4 presents the NDI per m^3 of irrigation water with increasing transaction costs. In the base analysis the agricultural sector utilises its full entitlement of 74 million m^3 of water from the DWAF. It uses approximately 36 million m^3 water for irrigation and the balance of 38 million m^3 is traded to the urban sector (see Figure 7.3). Figure 7.5 represents the demand for the water allocated to agriculture and the volume of water traded at different transaction cost scenarios.

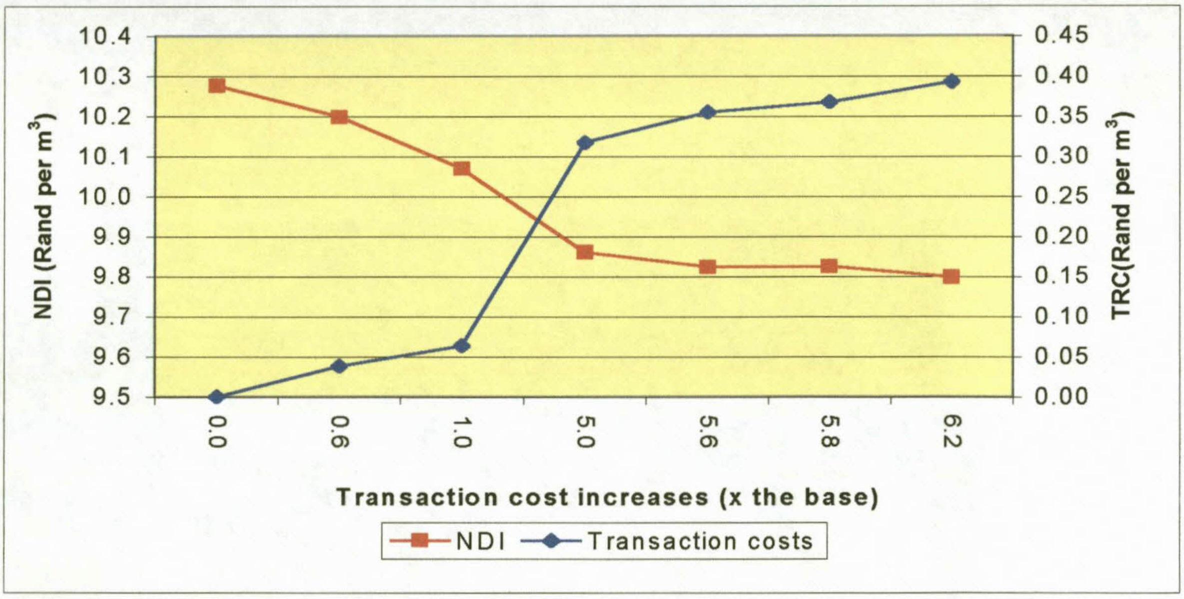

Figure 7.4: NDI per m^3 at different transaction cost trend (Rand per m^3)

It appears from Figure 7.4 that NDI per m^3 (measure of agricultural water use efficiency) deteriorates if farmers cannot trade the water that they do not use or need at present. On the other hand, the urban sector needs the water which however becomes too expensive due to high transaction costs imposed on the market. The eventual consequence is shown in Figure

7.5. The demand for the agricultural water allocation decreases because the incentive to trade is eroded. The Theewaterskloof Dam eventually has 40 million m^3 surplus water which nobody uses and the urban sector needs to build new water supply infrastructure at a high cost.

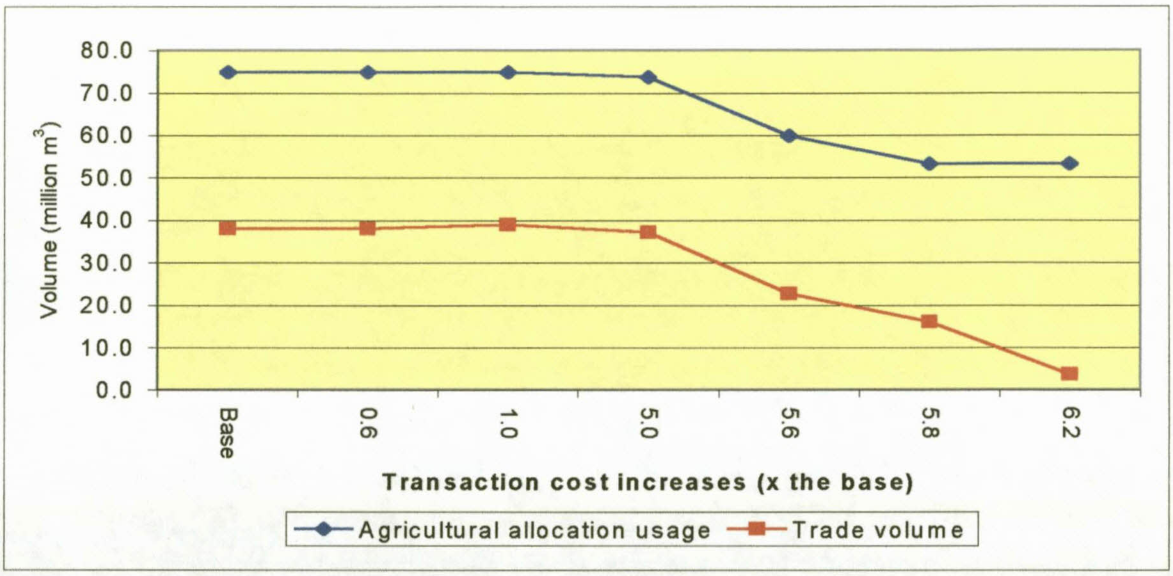

Figure 7.5: Agricultural usage of Theewaterskloof Dam water (million m^3)

Figure 7.6 confirms the situation. The volume of trade water decreases as the transaction costs increase and new sources are required to satisfy the demand.

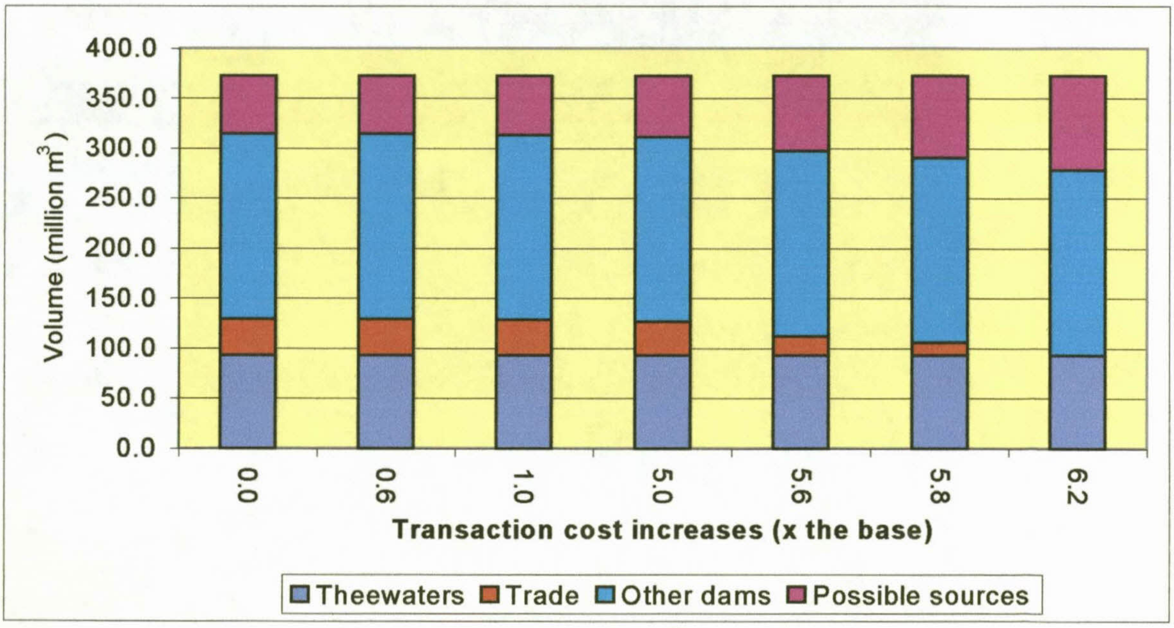

Figure 7.6: Urban water supply sources (million m^3)

This kind of scenario will probably never occur in a well-managed water market but the analysis shows that the market mechanism will not work with too high transaction costs. In Chapter 2 it was pointed out that many authors warned against the impact of such a situation and that high transaction costs could jeopardise the advantages of a water market regime. Most of the transaction costs found in water markets are, of course, also present in one form or another in other systems of water allocation. In addition, there are reasons to believe that the transaction costs associated with water marketing will be lower than the administrative costs associated with other allocative mechanisms because they are largely borne by the private sector, which has greater incentives to control costs and because the market generates at least some of the necessary information (Thobani, 1995). On the other hand, economies of scale could potentially reduce administrative costs in large centralised systems.

7.3.3 Water values

The impact of transaction costs on the marginal value of water for the agricultural as well as the urban sector is presented in Figure 7.7.

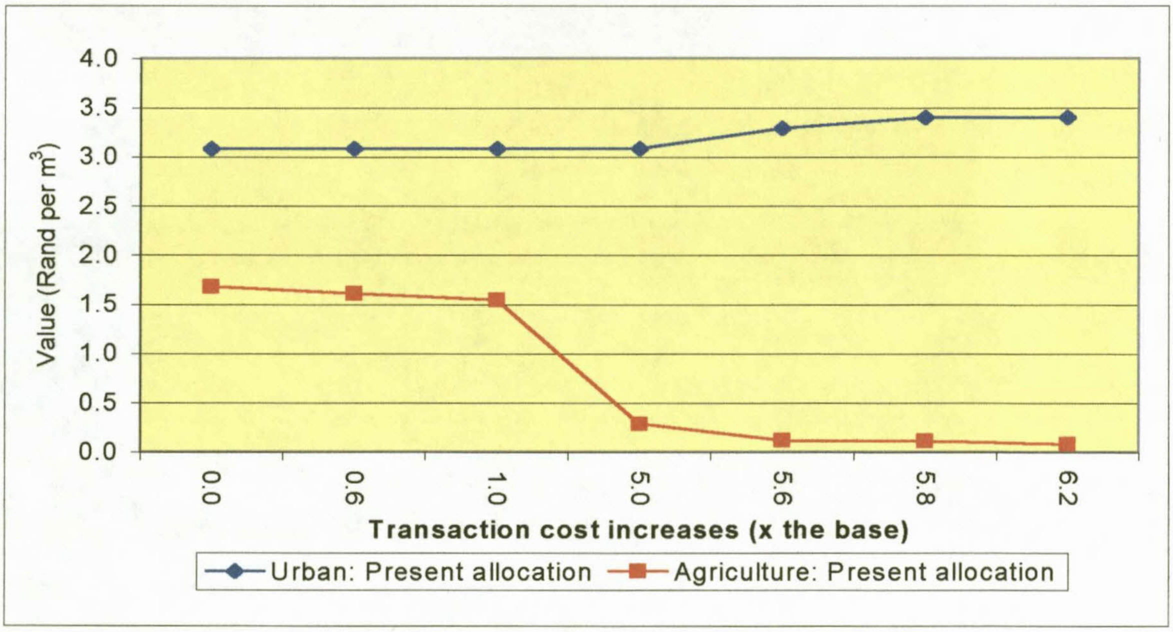

Figure 7.7: Urban versus agricultural water values (Rand per m^3)

It is clear that the value of water increases moderately in the urban sector after the 5.0 (32 cent per m^3) level. This is not surprising as the impact of excessive transaction costs is the creation of an artificial scarcity. The urban sector needs the water but the price is too high. A surplus of water is, on the other hand, created within the agricultural sector because agriculture cannot sell it due to the high transaction costs. Figure 7.8 presents the marginal value of other water sources and possible sources of the urban sector.

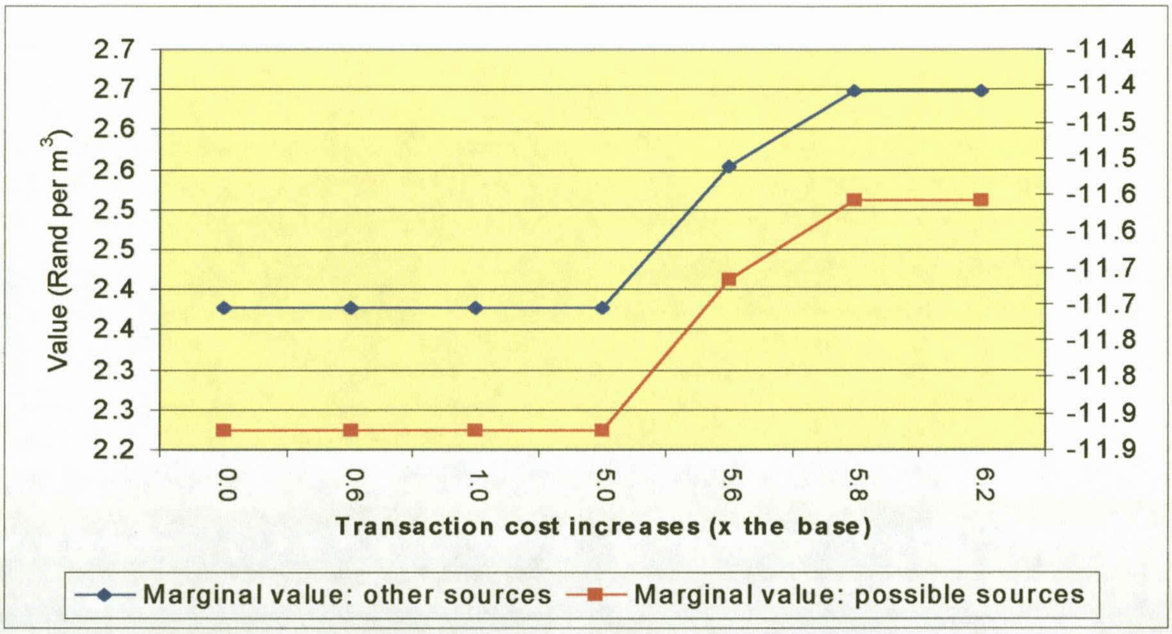

Figure 7.8: Marginal value of urban supply sources (Rand per m^3)

It is clear that when transaction costs exceed 5 times the base, the value of other sources increases dramatically because trade between the agricultural and urban sectors becomes too expensive; an artificial water scarcity is created by the high transaction costs.

Figure 7.9 presents the average value of agricultural water rights as transaction costs increase. The reason for the absence in trade of permanent rights within the structure of this model is clear. The static nature of the model prevents the water users from distinguishing between the advantages or disadvantages of permanent versus temporary trade. Although an attempt was made to treat this problem through a difference in transaction costs, it is obvious that the model will prefer the cheapest way of transferring water from one user to another. Higher transaction costs on permanent trade creates a permanent right scarcity. Figure 7.9 shows that the value of permanent rights is always higher than the value of temporary rights.

As soon as the transaction costs exceed 5 times the base value, the average marginal value of temporary rights becomes negative. This means that the objective function will decrease with this amount for every m^3 of temporary trade.

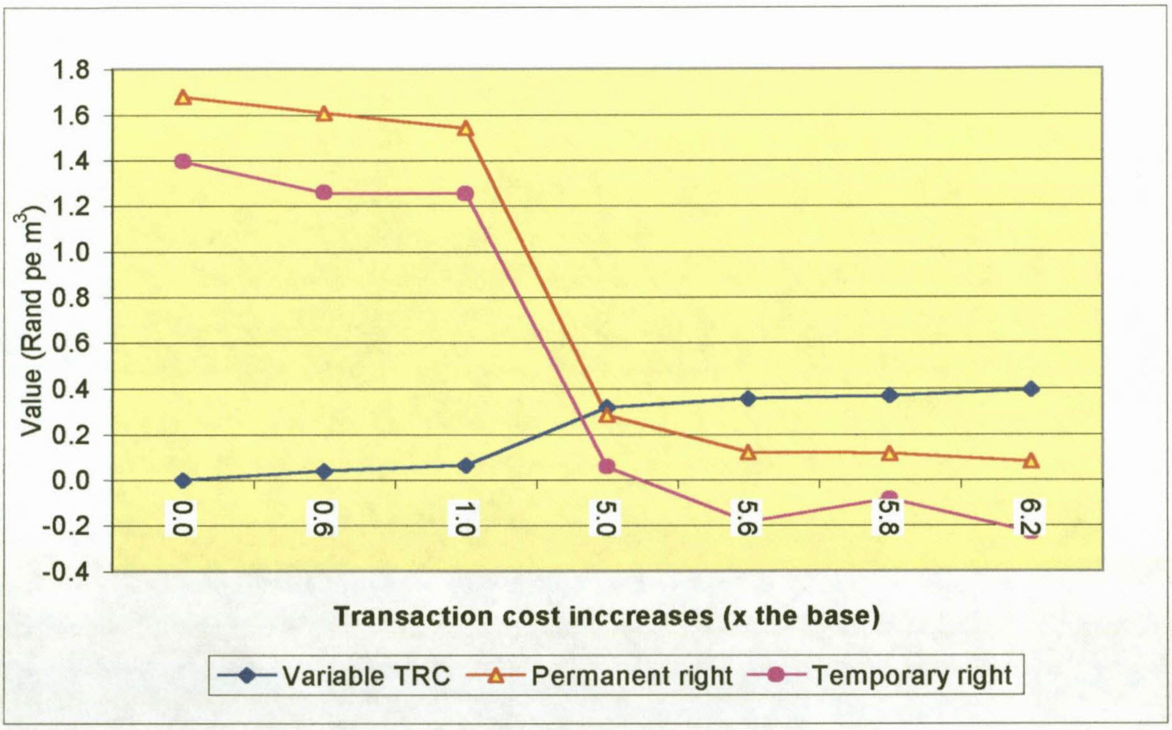

Figure 7.9: Average agricultural water right values and transaction costs

The upper limit to transaction costs for trade between the agricultural and the urban sector in the Berg River is about 6.2 times the base value. Table 7.2 presents the variable temporary trade transaction costs as a percentage of the urban value of water.

Table 7.2: Variable transaction costs, water right values and trade volumes

Item	0.0	0.6	1.0	5.0	5.6	5.8	6.2
Urban value (R/m^3)	3.1	3.1	3.1	3.1	3.3	3.4	3.4
Temporary variable TRC (R/m^3)	-	0.038	0.063	0.317	0.355	0.368	0.393
TRC as percentage of urban value	-	1.2%	2.1%	10.3%	10.8%	10.8%	11.6%
Agriculture to urban transfers (million m^3)	36.4	36.2	35.3	33.4	19.0	12.4	0.0

If the fixed transaction costs are ignored (relatively small amount compared to the variable cost) it is clear why no trade takes place after this point. The TRC of agricultural to urban transfers increases to more than 11.6 percent of the value of urban water. The result indicates that the results obtained in this study are consistent with that of the work of Garrido (1998).

Since market transactions are precipitated by the difference in the value of water in alternative uses and locations, which must be large enough to outweigh the costs of obtaining water through the market process, water markets will become active only where and when water is sufficiently scarce, and hence valuable. Conversely, water markets are unlikely to become active where many water rights remain unappropriated, where water supply investments continue to be favoured over reallocation, where transportation and transaction costs are very high, or where there are other sources of low- cost water.

7.4 Conclusion

It is clear that excessive transaction costs will erode the advantages of trade. If transaction costs are higher than the value that users attach to water, no trade will take place. Transaction costs can be used as an instrument by government to regulate unwanted water flows, e.g. the concerns about agricultural to urban water transfers as pointed out in Chapter 2. The individual does not take social welfare aspects into account when trading takes place. If the multiplier effects of agriculture are accepted as important for the local economy, government may wish to impose a higher transaction cost which can then be spent on services in the communities where the water was transferred from. In such a way the negative externality created by the transfer can be internalised.

Chapter 8

SUMMARY AND CONCLUSION

8.1 Introduction

This study focussed on the modelling of the potential impact of a water market. This included the methodology to analyse water markets as well as the quantification of variables, which will be influenced by the implementation of water markets as an alternative for administrative water allocation in the Berg River basin. The positive mathematical programming technique was introduced in the Upper-Berg River water allocation model. Several analyses were performed to quantify the effect of trade on the allocation of water, to illustrate the impact of transaction costs, to analyse the efficiency of water use and to quantify farmers' responses to tariff increases.

This chapter involves a summary and conclusion of the most important findings of this study, followed by suggestions for further research.

8.2 Summary of findings

The most important findings are summarised in four sections: modelling water markets, effect of trade on water allocation, trade, transaction costs and the efficient allocation of water.

8.2.1 Modelling water markets

a) The most important finding with regard to modelling is that in similar studies, without the PMP technique, response to policy and other external impacts on farmers' behaviour was probably overstated. The PMP technique causes a regional model, with incomplete information, to respond more smoothly to changes in parameters.

b) Traditional calibration approaches require calibration constraints that restrict the range of alternative scenarios; this limits their usefulness in policy analysis. The PMP approach uses the farmers' observed crop allocation in the base year to generate self-calibrating models of agricultural production and resource use, consistent with microeconomic theory, which accommodate heterogeneous qualities of land and livestock.

c) The spatial equilibrium modelling technique was found to be the best suited for this kind of research. However, as pointed out in Chapter 2, most of the previous studies used regional linear programming models instead of typical farms to represent the water demand functions for agriculture. In this study, typical farms are embedded in the spatial equilibrium model, and are aggregated to represent irrigation regions. This renders it possible to model farmers' behaviour more accurately.

d) Most other studies used total gross margins to measure farm profitability. In this study whole farm models are incorporated and the net disposable income (NDI) is used as measure of profitability. The NDI is a much more accurate measurement of farm profitability because it also includes overhead expenses, income tax, interest on loans and household expenses. Although depreciation should, according to the definition, also be subtracted from NDI, capital redemption on loans was included to provide for depreciation in an indirect way.

e) Most models used in similar studies concentrated on either the urban or the agricultural sector. In this model both sectors are incorporated in order to simulate the total water demand for the region. Through this integration, it is possible to capture the competition between agricultural users and urban users and to run scenarios which impact on both sectors. As will be pointed out in the next section, the opportunity cost of water can not be captured properly if sectors are modelled separately. The opportunity cost of water is critical in modelling the impact of water markets.

8.2.2 Effect of trade on water use efficiency and the allocation of water

a) Markets may allow water allocations to change in order to adapt to changing physical and economic circumstances.

b) Water markets act as buffer when water becomes scarcer. Water can be sold or leased to anyone for any purpose. This provides an incentive to the owners of the water right to conserve water and sell the surplus to those willing to pay a higher price than the value that the present owner attaches to the right, thereby allowing water to be reallocated to higher-valued uses.

c) When a water market is introduced the market sends price signals to users, informing them about the scarcity situation. The value of water increases and the opportunity cost of inefficient users becomes too high to carry on with their inefficient practices. They react by using water more efficiently. This creates "surplus" water which can be traded to higher-value uses.

d) The NDI per m^3 which was used as measurement of efficiency rises in response to the introduction of a water market.

e) In a water market regime farmers will change to lower-intensity irrigation as water becomes scarcer. When water trade is possible, farmers manage to keep a larger area under optimal irrigation than when it is not possible.

f) A no-trade policy regime is characterised by large differences in marginal values of water for different users. When a water market is introduced and reaches equilibrium, all water users' marginal value of water is the same. The only differences are caused by differences in transfer costs.

g) Water markets can also act as a buffer to keep urban water prices lower when restrictions are imposed. The modelling of urban water prices is over-simplified in this study since block tariffs for urban water have not been introduced. However, the results clearly indicated that in the absence of a water market the price of urban water will increase more rapidly than with a water market.

h) As water scarcity increases, a water market becomes more active. The volume of trade water increases relative to total consumption.

i) This study has also shown a close relationship between the volume of water traded within the agricultural sector and the volume traded between the agricultural and urban sectors. As scarcity increases, the volume of water traded within the agricultural sector decreases and the volume of water right transfers to the urban sector increases.

8.2.3 The impact of transaction costs on water trade

a) Transaction costs raise the market price of water and erode the advantages of trade with a subsequent decline in the volume of water transferred.

b) Transaction cost of more than 12 percent of the value of water will cause trade between the agricultural and urban sector of the Western Cape to decline drastically.

c) The NDI per m^3 declines substantially between zero and high transaction cost. Differential transaction costs between the urban and agricultural sectors with higher cost for the urban sector, impose an artificial water scarcity in the urban sector and an artificial "surplus" in the agricultural system. The value attached to water by the urban sector increases ("scarcity") while the agricultural value decreases ("surplus") with increasing transaction costs if differential transactions costs are applied.

d) If transaction costs are too high, not even unused water rights ("sleeper rights") will be transferred to other users who can use the water more beneficially. This can lead to major inefficiencies as new water supplies need to be developed even if there is a "surplus" of water in the system.

e) If the transaction costs for agricultural to urban water transfers are higher than for trade between irrigators, the trade volume to the urban sector will be reduced. The differential costs present a disincentive to intersectoral trade, and more water is available within the agricultural sector; farmers increase their irrigation intensity (produce higher-value crops) and the total NDI increases. However, there is a constant decrease in the NDI per m^3 which is an indication that differential and high transaction costs will decrease water use efficiency in the agricultural sector.

f) Market transactions occur when potential buyers and sellers both perceive that there are economic gains to be achieved by transferring water to a purpose, place or time of use in which it generates higher net returns than under existing use patterns. Transfers occur automatically whenever the net benefits from a reallocation are positive until marginal values are equalised among water users, uses and locations. Trade will continue until all water users are indifferent regarding buying or selling water rights.

g) Most of the transaction costs observed in water markets are also found in some form in other systems of water allocation. In addition, there are reasons to believe that the transaction costs associated with water marketing will be lower than the administrative costs associated with other allocative mechanisms, because they are largely borne by the private sector, which has greater incentives to control costs and because the market generates at least some of the necessary information (Thobani, 1995).

h) The question posed is whether high policy-induced transaction costs would drive the system closer to the social optimum? Eckert *et al* (1997) pointed out that agriculture, largely through its forward and backward linkages, plays a major role in the economy of the Western Cape. They used a social accounting matrix to calculate the fixed price multipliers of agriculture in the Western Cape. They found that for every R1 of additional demand for the horticultural sector's output the provincial value adding activity will be increased by R1.40; it will require R0.2 of additional inputs and contribute R0.24 to government revenue. In addition 92.8 person-years employment will be created per extra R1.0 million final demand. The agricultural sector contributes nearly 13 percent of the total formal sector jobs in the Western Cape. From a social welfare policy point of view it may therefore be sensible to introduce policy-induced water transfer restrictions for agriculture to urban transfers.

8.3 Conclusion

It was pointed out in Chapter 2 that the advantages of water markets as water allocation mechanisms are widely recognised. However, the question remains how a water market can be introduced in the Berg River or/and in other water catchments. Institutional arrangements set the ground rules for resource use. At worst, they establish impediments to efficient resource use and to compensate for their poor design significant resources must be expended.

Section 25(1) of the new National Water Act (1998) makes provision for the temporary transfer of water entitlements between users. However in the preamble to the Act it is clear that the approach to water management is to a large extent still centrally orientated:

"Recognising that while water is a natural resource that belongs to all people, the discriminatory laws and practices of the past have prevented equal access to water, and use of water resources. Acknowledging the National Government's overall responsibility for and authority over the nation's water resources and their use, including the equitable allocation of water for beneficial use, the redistribution of water, and international water matters."

On the other hand the Act contains many important aspects which will make it possible to introduce a water market:

- There is a clear division between land and water rights.
- The power and duty of the managing of water catchments will eventually be assigned to catchment management agencies (CMA) with representation of water user associations.
- A responsibility of the CMA's will be to prepare water allocation strategies for each catchment. It will therefore, with the approval of the minister, be possible to include water markets as a water allocation strategy in catchments.

To make progress towards the introduction of water markets a new approach to water management is needed; an approach that relies on a well-tuned balance between government regulation and market forces. Such an approach needs to include the following:

- The new National Water Act, 1998, will have to be amended to clearly state the rules and procedures for permanent as well as temporary water transfers. In the present Act water trade is only implicated by referring to the "transfer of water use authorisations".
- Water entitlements need to be clearly defined. The present licensing system provides for a licence that may be granted for a maximum of 40 years, renewable every 5 years with no guarantee that the user will receive the same volume of water. Although this is not necessarily a problem that will impede the functioning of a water market, especially for temporary transfers, the insecurity of tenure may lead to a lower valuation of water. This in return can increase the possibility of inefficiencies in the system because there will be less incentive to buy water.
- Without well-designed institutions, uncertainty about the physical quantity of water available at particular times and locations impedes efficient resource use by decreasing the expected value of engaging in water-related activities. The process of establishing water-user associations in the Berg River commenced during 2000. Shortly a CMA will be established. The Berg River CMA will have the opportunity to include water market principles in their allocation strategies. Institutions governing water use in general, and water markets in particular, can be structured in such as a way to accommodate externalities. Livingston (1998) pointed out that market failures could be prevented to a considerable extent in order to generate the security and flexibility that provide the foundation for efficient use.

- Water markets themselves tend to evolve over time. Even very simple water markets, if structured well, can be a stimulus for more efficient water use and can spawn continual refinements in the trading system. This concept was clearly indicated in this study. Even if the trade volume is low initially there are immediate gains in efficiency when water trade is permitted. The Berg River CMA can gain experience by instituting a relative simple water market (only internal trade within for example the agricultural sector) and develop over time into a sophisticated market with trade between all user sectors and even trade with other catchments (e.g. the Breede River and possibly the Olifants River).
- Livingston (1998) stated that ideally a private water organisation would facilitate efficient markets by:

    1) treating various water interests without bias;
    2) serving as a water broker, thereby lowering transaction costs of water trades;
    3) allowing the price of water to vary according to its changing economic value; and
    4) ensuring that water transfers do not impose uncompensated externalities on other water users.

In reality, water organisations exhibit every combination of policies imaginable but, in general, tend to move to greater recognition of market forces.

- Government agencies potentially involved in water transfers must not be biased towards any particular user group, otherwise water organisations may employ policies that disallow market functions. For example, it is fairly typical for water allocation during drought conditions to be decided through administrative rationing by public water organisations. In this case markets are not given the chance to generate the transfer from lower to higher-value use.
- Thobani (1998) stated that the most important reasons why water markets have not evolved, relate to the costs stemming from setting up a new legal, regulatory, and institutional framework; from defining, measuring and enforcing rights; and from making necessary changes in water intakes and conveyance infrastructure to effect the transfers. South Africa is at present setting up new structures to implement the new

National Water Act. This is a golden opportunity to establish institutions capable of handling market transactions.

- Within a water market regime great care must be taken to keep transaction costs as low as possible. When transaction costs are imposed to reach certain economic, social or environmental objectives, care must be taken to ensure that the revenue accrued from the transactions be applied to the benefit of the affected parties. In this way externalities are internalised and trade is still beneficial to all the affected parties.
- Water markets is a relative new concept for water users and the government in South Africa. Thobani (1997) pointed out that it is important to launch an information campaign to explain to users how formal property rights for water can help make their rights more secure and how water trading can result in mutual gains before a law establishing tradable water rights can be issued.

The importance of an integrated water management approach has been indicated in this study. It will not be possible to make appropriate water allocation decisions with models which do not incorporate all user demand sectors. The interaction between the value attached to water by the agricultural and the urban sectors and the effect thereof on trade (reallocation of water) was pointed out. Furthermore a key reason to use water markets as the reallocation mechanism within a water demand management strategy (such as currently being implemented by the government), is because they give both potential buyers and sellers an incentive to conserve water and to participate in bringing about an equitable and efficient water reallocation.

The study clearly indicated that the ability of water markets to reallocate water on a fair basis must not be underestimated. Easter *et al* (1998) pointed out that too often water trading is banned because the water resources have been developed with public funds and the water agencies do not want to lose control over water. There is also concern that poor farmers or households will be disadvantaged by water trading. The concerns about public resources and the poor are not very different from those that have been voiced in the past about land sales. The problem is that, in most cases, the poor already have limited access to resources. This is not a result of markets but rather of other things often centrally planned. Easter *et al* (1998) show that in India, water trading is likely to expand access to water for small-scale farmers.

Anderson (1982) pointed out that within a water market regime, the owners of water, who ignore the need to allocate water to higher-valued uses, would see their personal wealth decrease. Thus, knowledge and incentives would be linked. Water markets would send supply and demand signals that would enable managers to conserve water and co-ordinate its use, precisely the type of information that is conspicuously absent under centralised allocation (Anderson, 1982). This study indicated that even if trade volumes are low (when there is no real scarcity situation such as drought) a water market sends signals to users to allocate water to higher-value uses and thereby increase overall allocation efficiency.

Cummings and Nercessiantz (1994) pointed out that as supply and demand conditions change, the efficient allocation of the resource changes. The absence of market institutions to reallocate supplies in response to changing conditions and the importance of goods and services provided by water resources that are not traded and priced in markets are sources of potential discrepancies in the marginal values of water in alternative uses. This study pointed out that in the Berg River system, when trade is not permitted, there is a substantial difference in the marginal value of water between competitive uses, which indicates the inefficiencies in the allocation system. However, as soon as a water market is introduced all users value water equally as inefficiencies are removed from the system within the bounds set by the infrastructure. As soon as demand or supply conditions (e.g. growth in urban usage or water restrictions) change, the market performs an excellent task in reallocating water until the market is in equilibrium again.

The U.S. Office of Technology Assessment (1993) pointed out that efficiency gains through water markets could offset or postpone the building of large and costly structures needed to deal with increases demand. The results of this study suggest that although a water market cannot solve the looming water scarcities in the larger Cape Town area it can to a large extent relieve shortages through increased efficiency. The study pointed out that the introduction of a water market could extend the time of the building of the Skuifraam Dam and similar water augmentation schemes with several years. This will have important positive welfare implications for the affected people in that scarce financial resources could be reallocated for other important purposes.

Paterson (1987) pointed out that in the natural resources management field, appropriate application of markets calls for political choices that are not excessively coloured either by the neo conservative prejudice that markets can fix everything or by the liberal and environmentalist concern that markets are the stalking horse of political reaction.

Water in the Berg River catchment is an increasingly scarce resource. The opportunities of enhancing water supplies economically by building new water works is becoming more unpopular, environmentally as well as financially. Backeberg *et al* (1996) are of the opinion that there is substantial opportunity to ease the pressure of water scarcity by eliminating waste and improving the efficiency of water use. According to Backeberg *et al* (1996) the answer may be a market for water rights, subject to government control and regulation.

The study clearly indicated the potential advantages of a water market in the Upper-Berg River. However, attainment of the optimum is in practice much more complicated than in theory. Backeberg (1994) conducted a comprehensive study on the political economy of irrigation policy in South Africa. He concluded that political reform and democratic institutional changes are prerequisites for the transformation of water institutions. Also, policy options and institutions for willing negotiations and mutually beneficial agreements should be a high priority to implement market oriented allocation mechanisms. The National Water Act, (1998) is in some respects (separation of land and water rights) a move in the right direction but in others (the rules and procedures for instituting a water market) disappointing in spite of the appeal for water markets that was made in the negotiations prior to the approval of the Act.

8.4 Recommendations for further research

Further research on the following aspects is necessary:

a) **The development of dynamic spatial equilibrium models:** One of the major shortcomings of almost all the models developed to analyse water markets is their static nature. These models can at their best only provide the short-term response of water users to changes. The lack of dynamics in these models stems from the extreme complexity and the increase in model size when dynamics is introduced. For example, it was pointed out in this study that although the model provides for both temporary and permanent transfers, it cannot, due to its static nature, choose and allocate between the two alternatives. This would be possible in a dynamic model (with a planning horizon of more than one year). However, introduction of only one additional year in the model would have increased the number of water transfer variables substantially. Takayama (1992) pointed out that the introduction of dynamics in spatial equilibrium models still remains a challenge for researchers. Dynamic spatial equilibrium models will enable analysts to capture short, medium and long-term elasticities for water in the same model.

b) **The introduction of block tariffs for urban users**: Modelling the behaviour of urban consumers was oversimplified in this model. More research needs to be conducted to introduce block tariffs in the model. However, these tariffs apply to individual water users. Constructing typical urban water users within each of the urban sectors could offer a solution to increasing the accuracy of the model. Although the decision to buy or sell water rights in a water market regime will not be taken by an individual urban water user, the response to water price changes originates from individual users and not from the water utility.

c) **Yield-water relationships for a variety of crops:** This research field falls within the horticultural and agronomic sciences, not Agricultural Economics. For Agricultural Economists, such knowledge is very important in the quantification of the impact of water restrictions or on the strategies that farmers can apply to combat scarcities. Such research is, in any case, sorely needed by irrigators in their quest to use their scarce resources efficiently. The lack of research on yield-water relationships in South Africa can only be described as disturbing, considering the water scarcity in the country.

d) **The institutional rules and procedures to guide the introduction of water markets in specific catchments**: Although the experience with water markets in South Africa is limited, this situation is likely to change in future as more areas are faced with water scarcity problems and must look for better ways to reallocate water. Trades can lead to permanent or temporary reallocations. Easter et al (1998) pointed out that if the reallocation of water rights is permanent, or between sectors, formal markets will need to be developed. In contrast, if the reallocation is only temporary and within the agricultural sector, then informal markets will usually work. The characteristics of water markets will therefore not be the same for every catchment due to the specific characteristics of the catchments and the variation in water uses. In order to decide on what the rules and procedures should be, catchment specific research would have to be done.

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APPENDIX A

VERTROULIK / CONFIDENTIAL

NAVORSINGSPROJEK: WERKLIKE WAARDE VAN WATER EN DIE IMPAK VAN 'N POTENSIëLE WATERMARK IN DIE BERGRIVIER

RESEARCH PROJECT: THE TRUE VALUE OF WATER AND THE IMPACT OF A POTENTIAL WATER MARKET IN THE BERGRIVER

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ALGEMENE INFORMASIE / GENERAL INFORMATION

Produsent se naam / Producers name	
Adres / Address: Plaasnaam / Farm name	
Posbus / P.O. Box	
Town	
Code	
Telefoon / Phone	
Selfoon / Cellphone	
Faks / Fax	
Epos / Email	

PADBESKRYWING/DIRECTIONS TO FARM...
....
....
....
....

DIE INLIGTING WAT U VOORSIEN IN HIERDIE VRAELYS WORD AS VERTROULIK BESKOU EN SAL OP GEEN WYSE AAN 'N DERDE PARTY BESKIKBAAR GESTEL WORD NIE / THE INFORMATION PROVIDED BY YOU IN THIS QUESTIONNAIRE WILL BE TREATED AS CONFIDENTIAL AND WILL UNDER NO CIRCUMSTANCES BE MADE AVAILABLE TO A THIRD PERSON

1. Besitreg van grond in die Bergrivier / Property rights in the Berg River

Item	Eie grond / Own land	Huurgrond / Land rented	Om 'n deel bewerk / Sharecropping	Grond verhuur / Land rented
Oppervlakte / Area (ha)				
Oppervlak ingelys / Listed area (ha)				
Water kwota / Water quota (m^3 per ha)				
Oppervlak besproei / Area irrigated (ha)				
Droëland oppervlak/ Dryland area (ha)				
Veld / Natural grazing				
Werf en Uitval / Farmyard and odd				
Totale oppervlak /Total area				

2. Grondwaarde / Value of land

Waarde van vaste verbeterings uitgesluit / Value of fixed improvements excluded

Item	Markwaarde / Market value (Rand/ha)	Huurwaarde / Rent value (Rand/ha / jaar/year)
Besproeibare grond, onontwikkel met waterregte / Irrigated land, undeveloped with water rights? (Rand/ha)?		
Grond ontwikkel met waterregte / Developed land with water rights? (Rand/ha)?		
Wat is die markwaarde van nie-besproeibare grond / What is the value of non-irrigateable land (Rand/ha)?		
Waarde van veld / Value of natural grazing		
Waarde van werf en uitval / Value of farmyard and odd		

3. Grondgebruik binne die Bergrivier opvangsgebied (huur plus eie) / Land-use within the Berg river basin (own land plus rented land)

Gewas / Crop	Hektaar / Hectares	Tipe besproeiing / Irrigation system
Besproeiing / Irrigation		
Wingerd / Vineyard		
Perskes / Peaches		
Pruime / Plums		
Sagtesitrus / Softcitrus		
Koejawels / Guava		
Appelkose / Appricots		
Olywe / Olives		
Ander / Other:		
Ander / Other:		
Groente / Vegetables		
Droëland / Dryland		

4 Produksie inligting / Production information (Langtermyn gewasse / Long-term crops)

4.1.1 Wat is die gemiddelde boomaanplantings per ha / What is the average tree plantings per ha?

Dui asseblief die cultivar in die blokkies onder die gewas aan en direk daaronder die aantal bome / Please indicate the cultivar in the space provided and directly below that the number of trees.

Wingerd /Vineyard	Tafeldruif/ Tablegrapes	Perskes /Peaches	Pruime /Plums	Sitrus / Citrus	Koejawel / Guava	Appelkose / Apricots	Olywe / Olives	

4.2 Langtermyn gewas informasie / Long-term crop information

Indien u meer as een cultivar van dieselfde gewas verbou dui asb. die gewas in die eerste ry bo aan elke kolom aan en die cultivar direk daaronder. Byvoorbeeld: Wyndruiwe en Cabernet Souvignon / If you cultivate more than one cultivar of the same crop please indicate the crop in the first row at the top and the cultivar directly beneath it.

	1	2	3	4	5	6	7
Gewas / Crop							
Cultivar							
D of B							
Ouderdom/Age Jongste/Youngest							
Ouderdom/Age Jongste/Youngest							
Gem opbrengs/ Average yield							
Price (1999/2000): Export							
Price (1999/2000) Export							
1999							
Ha							

	8	9	10	11	12	13	14
Gewas / Crop							
Cultivar							
D of B							
Ouderdom/Age Jongste/Youngest							
Ouderdom/Age Jongste/Youngest							
Gem opbrengs/ Average yield							
Price (1999/2000): Export							
Price (1999/2000): Export							
1999							
Ha							

	15	16	17	18	19	20	21
Gewas / Crop							
Cultivar							
D of B							
Ouderdom/Age Jongste/Youngest							
Ouderdom/Age Jongste/Youngest							
Gem opbrengs/ Average yield							
Price (1999/2000): Export							
Price (1999/2000): Export							
1999							
Ha							

	22	23	25	26	27	28	29
Gewas / Crop							
Cultivar							
D of B							
Ouderdom/Age Jongste/Youngest							
Ouderdom/Age Jongste/Youngest							
Gem opbrengs/ Average yield							
Price (1999/2000): Export							
Price (1999/2000): Export							
1999							
Ha							

4.3 Korttermyn gewasse: besproeiing / Short-term crops: irrigation (1999/2000)

Gewas / Crop	**Oppervlakte / Area**	**Opbrengs / Yield (ton per ha)**	**Bruto inkomste per ha / Gross income per ha**

4.4 Korttermyn gewasse: droëland / Short term crops: dryland (1999/2000)

Gewas / Crop	Oppervlakte / Area	Opbrengs / Yield (ton per ha)	Bruto inkomste per ha / Gross income per ha

4.5 Veevertakkings / Livestock enterprises

Item	Skape / Sheep		Vleisbeeste		Melkbeeste		Ander	
	Aantal	Waarde	Aantal	Waarde	Aantal	Waarde	Aantal	Waarde
Ooie/koeie Verse								
Ramme/bulle								
Hammels/ Kapaters/Osse Tollies								
Lammers Kalwers								
Totaal								

4.6 Besproeiingsstelsel en dam opgaarkapasiteit / Irrigation system and dam capacities

4.6.1 Besproeiingstelsel / Irrigation system

Dui asseblief die vernaamste stelselkapasiteit beperkings aan, beginnende by die mees beperkendste / Please indicate the most limiting capacity constraints within your irrigation system.

Item	**Leweringskapasiteit m^3 per ha per uur of mm per uur per ha / Delivery capacity in m^3 per hour or mm per hour**
1.	
2.	
3.	
4.	
5.	

4.6.2 Dam kapasiteit / Dam capacity

Let asseblief daarop dat die inhoudsmaat nie noodwendig die leweringskapasiteit van die dam is nie aangesien die dam meer as een keer per jaar opgevul kan word / Please note that the storage capacity and the average annual delivery capacity is not necessarily the same as the dam can be filled more than once during the same year.

Dam	**Inhoudsmaat / Storage capacity (m^3 X 1000)**	**Gemiddelde veilige jaarlikse lewering / Average annual delivery capacity (m3 X 1000)**	**Bron / Source ***
1.			
2.			
3.			
4.			
5.			

* Dui asseblief by die bron aan watter persentasie van water in die dam uit u inlysting vanuit die Bergrivier aangevul word en watter is uit natuurlike opvang (byvoorbeeld 80% dui daarop dat 80% van die water uit die Bergrivier kom) / Please indicate at the source the percentage of water being pumped from your listing out of the Berg River and the amount from natural runoff (for example 80% indicates that approximately 80% is being pumped from the Berg River)

5. Arbeid / Labour

5.1 Permanente arbeid: Samestelling, aantal en vergoeding / Permanent labour: Composition, number and renumeration

Pos-titel / Titel	Aantal / Number	Per maand / per month		Per Jaar / Per year				Totaal/jaar Total / year
		Kontant Loon/ Cash	Gekoopte rantsoen / Rations	Klerasie / Clothes	Medies / Medical	Ongevalle versekering / Accident insurance	Bonus	

5.2 Tydelike arbeidsmag (Seisoenarbeid) / Casual labour

Doel waarvoor benodig / Purpose	Aantal / Number	Tydperk / Period	Vergoeding / Remuneration

6. Oorhoofse boerdery-uitgawes / Overhead costs

Item	Bedrag / Amount
Gehuurde bestuurskoste / Hired labour	
Waterbelasting / Water tariffs	
Bakkie en vragmotor brandstof / LDV and truck fuel	
Elektrisiteit / Electricity	
Distriksraad belasting / District council levies	
Bankkoste/Bank costs	
Versekering op vaste verbeterings/ Insurance of fixed improvements	
Reparasies op vaste verbeterings / Repairs on fixed improvements	
Sekuriteit / Security	
Konsultasie / Conseltation	
Telefoon en selfoon / Telephone and cell phone	
Sekretariële dienste / Secretarial services	
Grondhuur / Land rent	
Diverse / Other Boekhougelde vir ouditeursfooie / Accounting .... - Skryfbehoeftes en tydskrifte / Stationery and magazines............. - Telefoon en posbus / Telephone and postoffice.......................... Lede- en intekengelde / Membership and subscription fees.........	 ....
Ander (spesifiseer) / Other (specify)	 ....
TOTAAL / TOTAL	

7. Korttermyn lenings / Short-term loans (1999)

Beskrywing (Tipe lening bv. Oortrokke) / Description (Type of loan e.g. Overdraft)	Kredietlimiet / Credit limit	Totale Rente betaal /Total Interest paid (1999)	Rentekoers (bv. Prima plus een) / Interest rate (e.g. Prime plus one	Gemiddelde maandelikse saldo / Average monthly balance
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				

13. MEDIUM- EN LANGTERMYN LENINGS / MEDIUM AND LONG-TERM LOANS

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
Finansieringsinstelling / Institution	Jaar Aan gegaan / Year	Doel (Beskryf volledig) / Purpose	Termyn (Jare) / Term (Years)	Rentekoers / Interest rate (i)	Voorwaardes (Spesifiseer) / Conditions (ii)	Oorpronklike bedrag / Original amount (iii)	Rente vooruit betaal / Interest paid in advance (iv)	PAAIEMENT / INSTALLMENT				UITSTAANDE / OUTSTANDING		Agterstallige bedrag / Outstanding amount (vi)
								Kapitaal / Capital	Rente / Interest	Assuransie / Insurance	TOTAAL / TOTAL	Bedrag / Amount (v)	Termyn / Term	

(i) Nominale rentekoers / Nominal interest rate.

(ii) Grootte van deposito, maandeliks voor- of agteruitbetaalbaar, amortisasie, dalende rente of vaste rente / Deposit, monthly pre-paid or end of month, amortisation, declining interest rate or fixed interest.

(iii) Sonder gekapitaliseerde rente / Without capitalised interest.

(iv) Huurkooptransaksies / Hire purchase transactions.

(v) Uitstaande kapitaal van oorspronklike bedrag / Outstanding capital on original amount.

(vi) Paaiemente en/of rente nog nie betaal nie / Instalments and/or interest not paid to date.

VERTROULIK / CONFIDENTIAL

WAARDASIE VAN DIE BOERDERY-EENHEID / VALUATION OF THE FARM UNIT

VASTE VERBETERINGE/FIXED IMPROVEMENTS

L.W. ***Slegs die waardes van vaste verbeteringe word hier ingesluit. Die waardes van toerusting word onder gereedskap aangedui.***

N.B. ***Only the values of fixed improvements are included here. The equipment is taken into account further on.***

	Huidige waarde/Present value		*Slegs vir kantoorgebruik/ For office use only*
	Op eie plaas/ On own farm	*Op gehuurde plaas/ On hired farm*	
BEHUISING/ACCOMMODATION: *Bestuur/Management*			
Arbeid/Labour			
PLAASGEBOUE/FARM BUILDINGS *Melkportaal/Milking parlour*			
Store/Sheds			
Pakstore/Packing sheds			
Stalle/Stables			
Varkhokke/Pigsties			
Pluimveehokke/Poultry runs			
Dip en drukgange/Dip tanks			
KRALE/KRAALS			
OMHEININGS/FENCES: (BINNE/INSIDE)			
(BUITE/OUTSIDE)			
BESPROEIING/IRRIGATION			
WATERVOORSIENING/WATER SUPPLY			
Windpompe/Windmills			
Boorgate/Boreholes			
Reservoirs			
Sementdamme/Cement dams			
Gronddamme/Earth wall dams			
Pype en veesuipings/Pipes and drinking troughs			
NIE-BOERDERY/ NON-FARM			
Woonhuise/Farm houses			
Plaaswinkel/Farm shop			
TOTALE WAARDE VAN VERBETERINGS/ *TOTAL VALUE OF IMPROVEMENTS*			

TOTALE WAARDE VAN BOERDERY/TOTAL VALUE OF FARM UNIT

Vaste verbeterings/Fixed improvements: ....

Grond/Land (Bladsy 2/Page 2) ....

TOTAAL/TOTAL: ....

VERTROULIK / CONFIDENTIAL

INVENTARIS/INVENTORY

Fabrikaat en model (jaar) *Make and model (year)*	*Huidige waarde* *Present value*
MOTORS/MOTOR CARS	
BAKKIES/LDV'S	
VRAGMOTORS/TRUCKS	
MOTORFIETSE/MOTOR CYCLES	
VLIEGTUIE/AEROPLANES	
TREKKERS/TRACTORS	
STOOTSKRAPER/BULLDOZER	
SELFAANGEDREWE STROPER/ *AUTO COMBINE*	
IMPLEMENTE / IMPLEMENTS	
POMPE, MOTORS EN FILTERS, PUMPS MOTORS AND FILTERS	
GRONDVERSKUIWINGSMASJIENE / EARTHMOVING EQUIPMENT	
PLANTER/PLANTER	
SPUITMASJIENE / SPRAY MACHINES	
HOOI TOERUSTING / HAY EQUIPMENT	
LEWENDE HAWE TOERUSTING / LIVESTOCK EQUIPMENT	
SLEEPWAENS / TRAILERS	
WERKSWINKEL / WORKSHOP	
KANTOOR TOERUSTING / OFFICE EQUIPMENT	
VOORRADE SELFGEPRODUSEER / FARM PRODUCED STOCKS	
GEKOOPTE VOORRAAD / PURCHASED STOCKS	
DEBITEURE / SUNDRY DEBTORS	

APPENDIX B

MODELLING METHODOLOGIES

B.1 The "standard " spatial equilibrium approach

Jones and Fagan (1996) pointed out that by considering Figure B.1 where part (a) presents the market equilibrium for volumetric allocation use and Figure B.2 the equilibrium for trade water. The right-hand section of Figure B.1 illustrates the excess demand *(ED)* and excess supply *(ES)* functions for irrigation water which determine the level and flow of trade in irrigation water. On the y-axis P_v represents the price for volumetric allocation and P_t the price for trade water (where trade water, TWE and excess demand are the same commodity). *D* is the demand function for irrigation water, P_l is the fixed charge per unit of volumetric allocation and *V* is the available volumetric allocation of water for an irrigation region which can be interpreted as an annual quota on water use in the region. The true supply curve for irrigation water is unknown, with individual irrigators being faced with the administratively set artificial supply function of *P* with a fixed marginal cost of P_l for volumetric allocation supplies. The excess demand and excess supply functions are derived from the demand function *D* and the volumetric allocation constraint *V.*

Under the current institutional setting, irrigation water consumption is at Q_l at the prevailing price P_l. If the quota constraint on volumetric allocation were relaxed, irrigation water consumption would be at *Q2* where marginal cost equals marginal revenue. The actual demand function for irrigation water from volumetric allocation supplies is the segment *ab* of the demand function *D.* At Q_1 the marginal revenue from water consumption exceeds the marginal cost and it would thus pay to obtain additional supplies of water. The segment *bc* of the demand function *D* is an excess demand function and can thus be considered the demand function for TWE, or imported water, which is additional to that available from the volumetric allocation (as measured by its demand function *ab).* This same function is represented in Figure B.1 by the excess demand function *ED.* At price P_{vl} the demand for TWE water is zero while at P_l, OQ_{tl} (or Q_2-Q_1) is demanded. The minimum price of TWE water is unlikely to be below P_l after the costs of supply and distribution in that region, transport costs and translation factors (transmission losses) are accounted for.

It should be noted that for the purpose of simplicity Figure B.1 has been drawn assuming that the price of TWE water, P_t, equals the price of volumetric allocation water, P_1. P_t will in fact not equal P_1, but will vary in a competitive market above P_1. If the volumetric allocation quota, V, in Figure B.1 intersected the curve *P* to the right of the function *D*, then the water constraint would become non-binding, there would be a surplus in the volumetric allocation which results in there being no possibility of an excess demand function for irrigation water.

The curve *ES* in Figure B.1 represents an excess supply function for volumetric allocation, which could be made available for sale through a TWE scheme. This excess supply function is the inverse of the demand function *D* for the quantity range $0Q_1$. It is therefore dependant not only upon the functional form of *D* but the level of volumetric allocation V. At a price of P_{v2} demand is zero, meaning $0Q_1$, (or $0Q_{t2}$) is excess supply at that price. At a price P_{v1} the demand function intersects *V* and excess supply is zero. In this problem *ES* and *ED* are a direct function of *D* and *V* and can be algebraically determined once these two functions are known. Consider where:

(1) D is $p_w = \alpha_w - \beta q_w$

(2) *ED* is $p_m = \alpha_m - \beta q_m$

(3) *ES is* $p_x = \theta_x + \gamma q_x$

and $V = Q_1$

In this particular problem as we are dealing with a limit on supply, the slopes of *D*, *ED* and *ES* are equivalent except that the sign is reversed for ES i.e. $\gamma = -\beta$. To estimate *ED* and *ES* is simply a matter of determining the intercept when q_w is equal to Q_1. Thus

(4) $p_m = (\alpha_w - \beta Q_1) - \beta q_m$

(5) $p_x = (\alpha_w - \beta Q_1) + \gamma q_x$

The level of consumer surplus is measured by the areas *abde* + *fgh*, assuming $P_t = P_v$. In the first area the relevant price is P_v while in the latter area the relevant price is P_t. Producer surplus is measured by the area *hij*, assuming $P_t = P_v = P_{v2}$. The areas fgh and hij represent the maximum consumer surplus and producer surplus from trade in irrigation water that can be derived under alternative price scenarios.

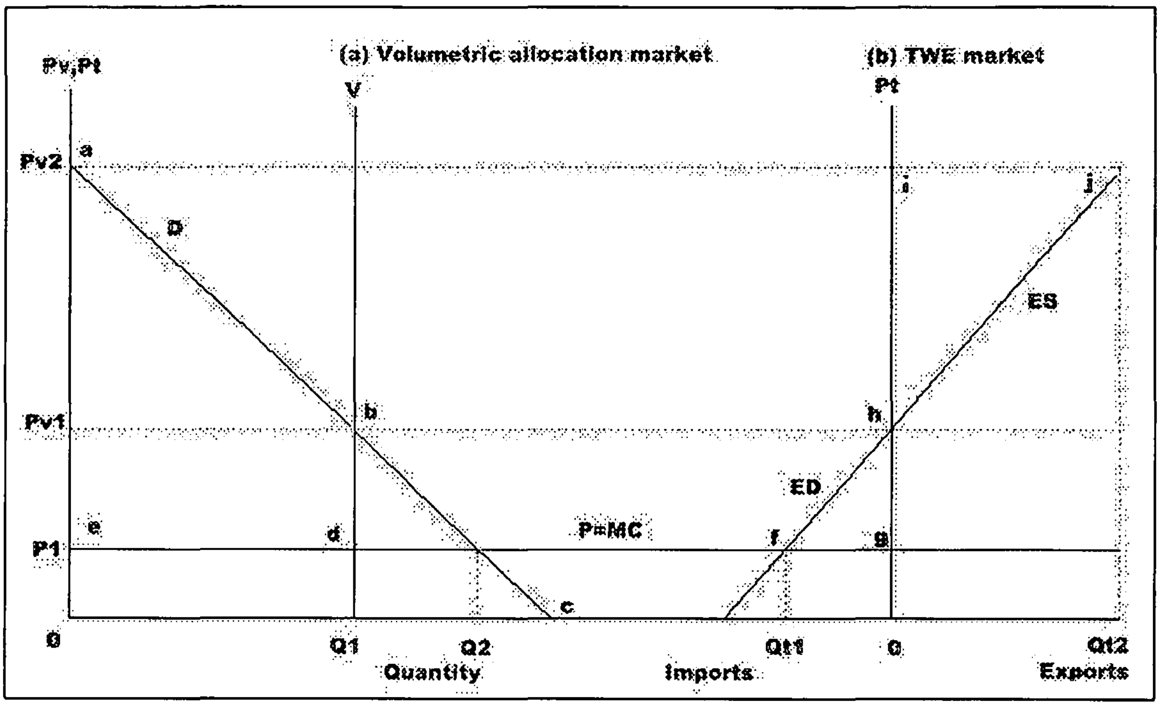

Figure B.1: Market equilibrium for volumetric allocation

Consider in Figure B.2 two alternative water trade price scenarios, P_{t1} and P_{t2}. At the water trade price of P_{t1} all volumetric allocation is still used, Q_1 at price P_1, however an imported volume of TWE water of $0Q_{t3}$ (or Q_4-Q_1) will be consumed at the price P_{t1}. The relevant economic surplus areas are a consumer surplus measured by the areas of *abde* + *hmn*. Producer surplus is zero as no water is sold from this region at P_{t1}. When water trade price becomes P_{t2} it has reached a sufficient level to attract sales of water from the region of $0Q_{t4}$ (or $Q_1 - Q_3$). This leaves consumption of water in the region at $0Q_3$, at the fixed price P_1. The relevant economic surplus areas are now a consumer surplus area of *akle* and a producer surplus area of *hop*.

The important point from the presentation in Figure B.2 is that at any one equilibrium price a region can be a net buyer or net seller of TWE water, not both. The value of the TWE water will govern whether a regions buys or sells water.

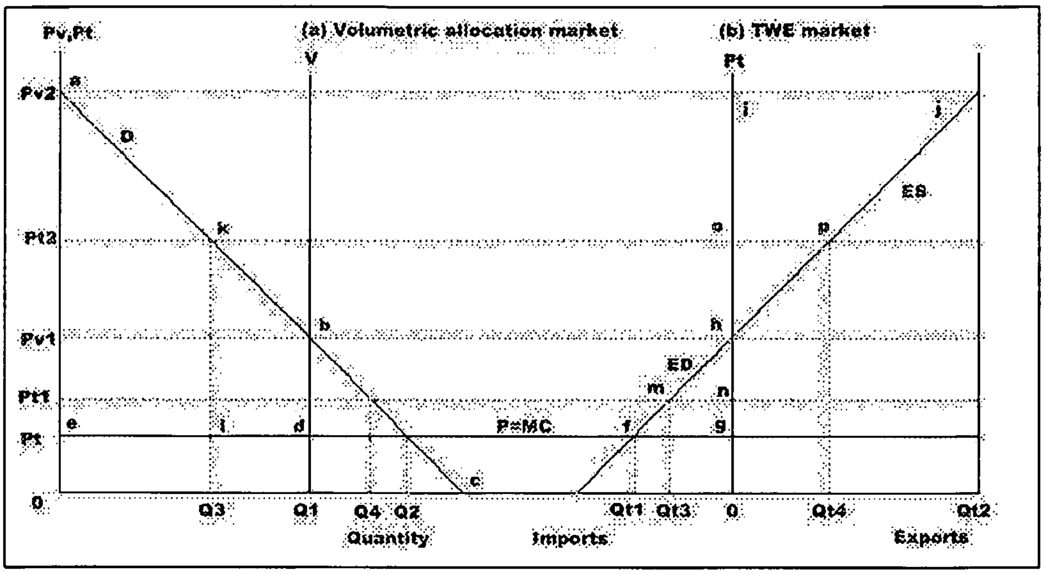

Figure B.2: Water trade with differing trade prices

Consider now Figure B.3 where the volumetric allocation constraint *V* has been shifted to the left to V_1 as a result of a particular policy change, such as the reallocation of irrigation water by a supply authority. Although the demand for water, *D*, remains unchanged ED and ES have been shifted to ED_1 and ES_1. The demand function for volumetric allocation is *ak* instead of the previous *ab*, and the demand function for TWE is now represented by the segment *kc* (a shift to the right). Consumer surplus is now measured by the area *akle* + *mgn* and producer surplus is *nio*.

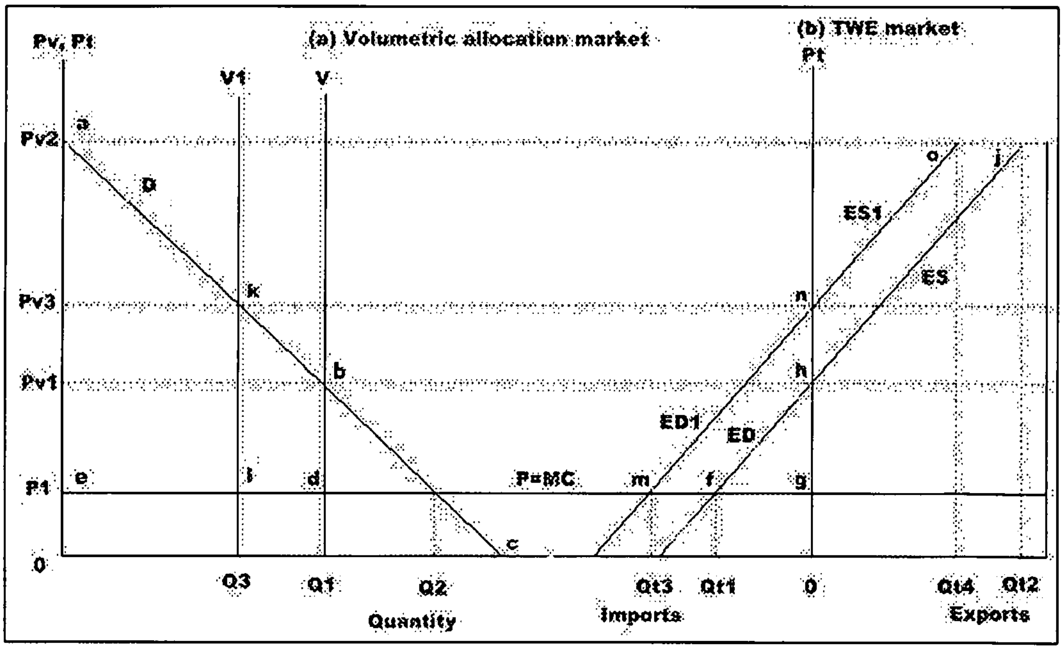

Figure B.3: Water trade with reduced volumetric allocation

The objective function with the "standard" spatial equilibrium approach is to maximise total welfare (consumer plus producer surplus). According to Gardner and Fullerton (1968) maximum productive efficiency can be said to exist when the factors of production are used in optimal proportions with optimal technology and are applied to those uses where total value product is maximised. The economic welfare of the owners of production is a function of the productive efficiency of the factors, and, in turn, the economic welfare of the community is a function of the welfare of the factor owners. Theoretically, provided that there are no externalities, each factor will be allocated optimally when the values of marginal product of that factor in various uses and among competing users are equal. In a perfectly competitive market in equilibrium, factor prices will be equal to the values of marginal product for all factors.

B.2 The primal-dual formulation for spatial equilibrium models

Eigenraam *et al* (1996) illustrated the net social revenue objective function of the primal-dual formulation, for a two-region economy with one product being traded by using the following notation as valid:

Region 1 = 1
Region 2 = 2
S= Regional supply
D = Regional demand in region
ES = Excess supply
ED = Excess demand
Qs = Supply quantity
Qt = Quantity traded
Qd = Demand quantity
Pt = Trading price
P1 = Price in Region 1
P2 = Price in Region 2
Tr = Per unit transport cost
c = optimal solution (Net revenue = 0)

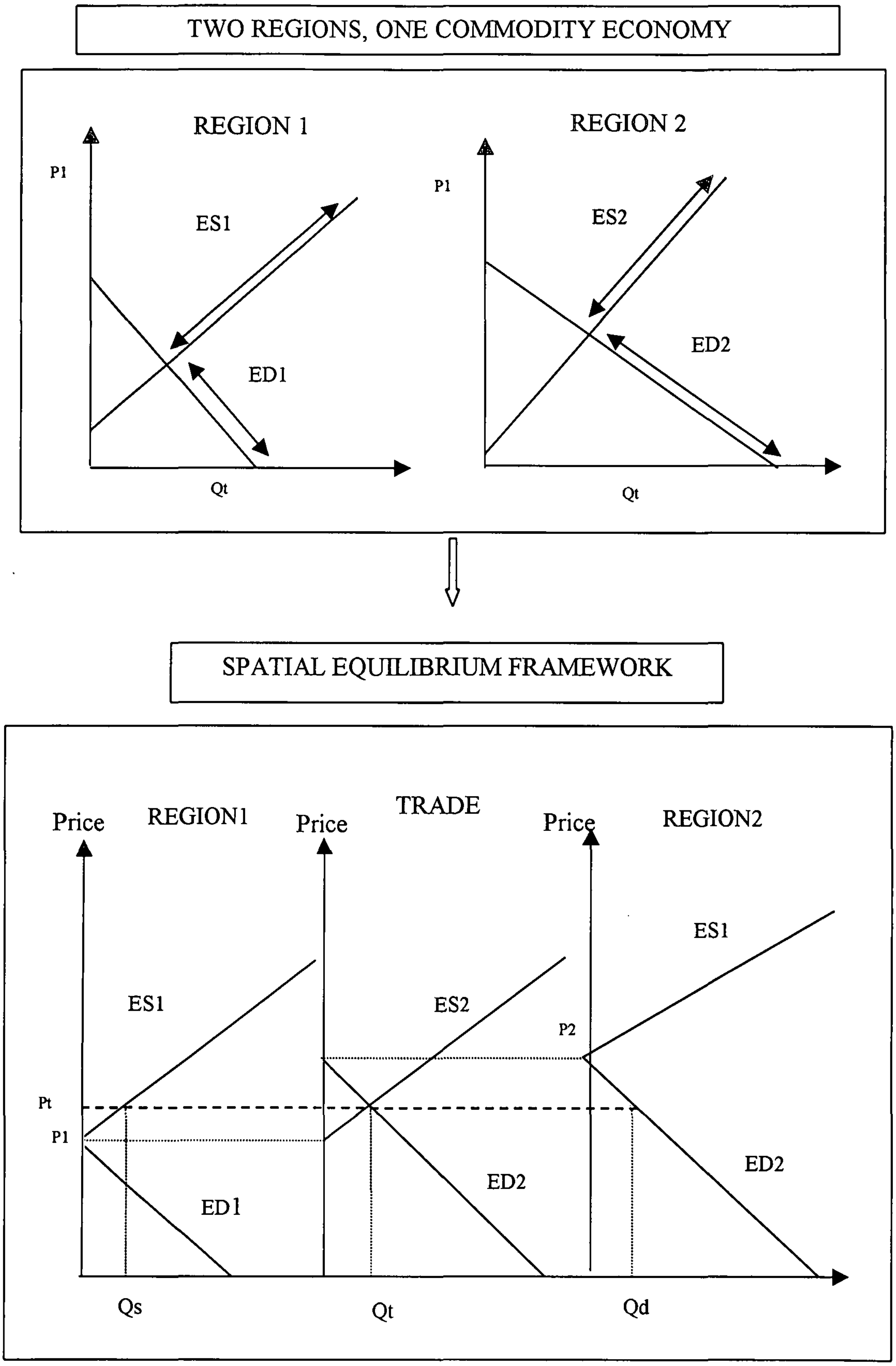

Figure B.4: Spatial equilibrium conceptual framework

It is clear from Figure B.4 that trade will occur between the two regions where excess supply (ES) equates excess demand (ED). The maximum volumes of a commodity that can be supplied by a system if the commodity price was not a limiting factor are limited by the fixed resource restrictions. The excess supply is the difference between this maximum and the volume being produced at the present price. The excess demand can be defined in similar fashion. Excess demand for water is for example the volume of water that can be used profitably but which is in excess of the of the water currently available. Region two has the highest price intercept P2 therefore the excess demand curve will be based on this region's demand curve. Similarly Region 1 can supply at a lower price and therefore will determine excess supply. In Figure B.2 this occurs at Pt with the quantity traded equal to Qt. The direction of trade will be from the lower-priced region to the higher-priced region as long as the price difference between the two regions is greater than the transport and transaction costs. According to MacAulay, Batterham and Fisher (1989) net social revenue can be defined as the revenue obtained from the volume of a commodity transported between two regions (trading price x volume) minus the transport cost (average transport cost x volume).

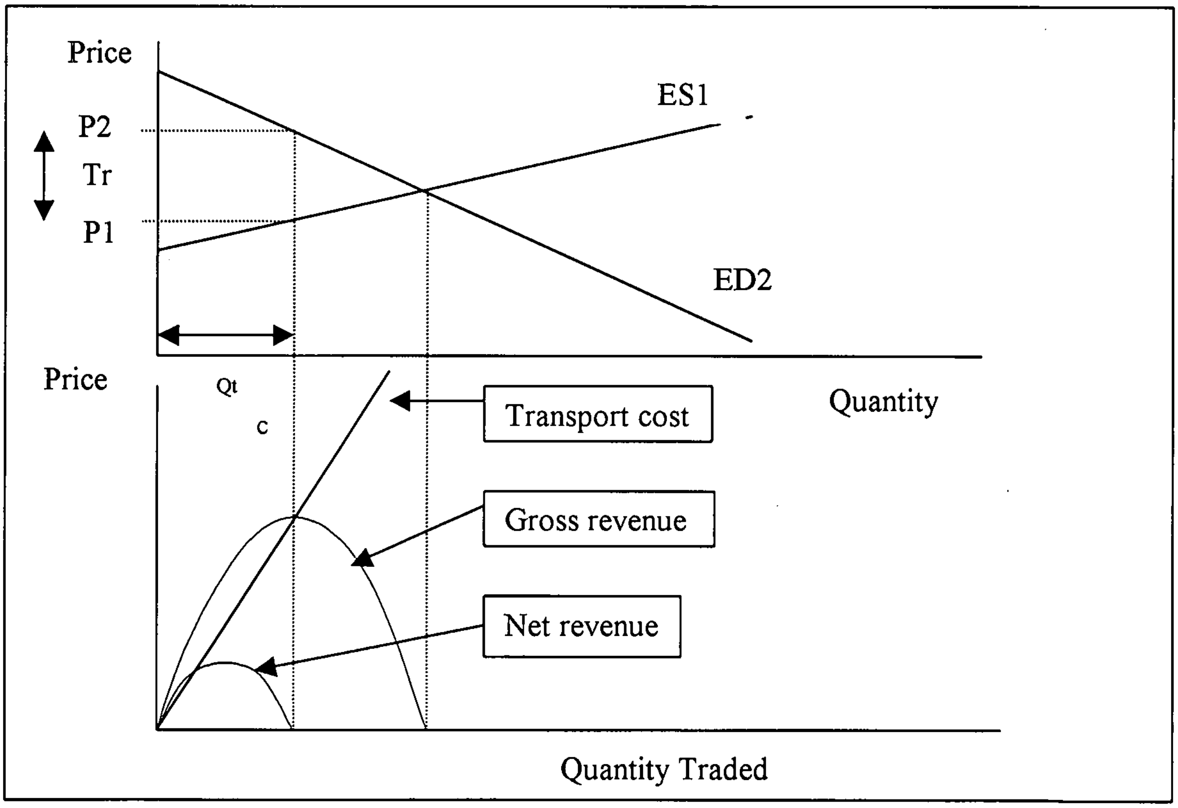

Figure B.5: Net social revenue maximisation

The calculation of net social revenue is presented in Figure B.5 (Eigenraam *et al*, 1996). The same notation is valid as for Figure B.4 with the addition of Tr and c.

If the vertical difference between the excess supply and demand curves is plotted, the quantity traded is obtained. The relationship represents the demand for transfer services (volume). This curve is downward sloping since it relates the quantity of goods that will be shipped at any level of differences in prices between the two regions up to the point where no trade would take place or the direction of trade will be reversed. The gross revenue to be gained by arbitrage at every level of trade is derived by multiplying the price difference by the level of trade in its quadratic form. The total transport cost is obtained by multiplying the per unit transport cost (Tr) with the volume of trade so as to obtain a linear function for trade. Subtracting the total transportation cost from the gross revenue obtained by trade derives the net social revenue. An important feature of this model is the assumption that arbitrage bids away any profits to be made in transferring the goods so that at equilibrium (Qt, P1 and P2) the net social revenue is zero.

B.3 The positive mathematical programming approach

Heckelei (1997) described PMP as a methodology to calibrate linear programming (LP) models to observed quantities by using information contained in the dual variables to specify appropriate non-linear objective functions. The attractiveness of the exact calibration property combined with the promise to constrain the simulation behaviour of the models less severely than previously employed approaches (with bounds) lead to a significant interest and continuing implementation of this approach in the area of agricultural sector modelling.

Consider the following profit maximisation linear programming model:

$$\text{Max}Z = p'x - c'x$$

(1) subject to

$$Ax \leq b \qquad [\pi]$$

$$x \geq [0]$$

where

Z = Objective function value
p = (n'1) vector of product prices
x = (n'1) vector of production activity levels
c = (n'1) vector of variable cost per unit of activity
A = (m 'n) matrix of coefficients in resource constraints
b = (m '1) vector of available resource quantities
π = vector of dual variables associated with the resource constraints

This problem is a typical representation of a farm or regional LP model. The solution to this problem will very seldom solve to reproduce the observed activity levels. In almost all cases overspecialisation will occur because the number of observed resource constraints is usually below the number of observed activities and the number of nonzero activities is upper bounded by the number of resource constraints.

According to Heckelei (1997) the basic PMP approach consists of two steps. In step one calibration constraints are used to force the optimal solution of the LP model to exactly reproduce the observed base year activities. Consider the following extended model (1) problem:

$$\text{Max}Z = p'x - c'x$$

(2) subjected to

$$Ax \le b \qquad [\pi]$$
$$x \le (x^0 + \varepsilon) \qquad [\lambda]$$
$$x \ge [0]$$

where

x^0 = (n'1) vector of observed activity levels
ε = (n'1) vector of small positive numbers
π = dual variables associated with resource constraints
λ = dual variables associated with the calibration constraints

According to Arfini and Paris (1995) the PMP methodology was developed in the late 70s essentially as an outgrowth of the observation that it is easier to collect information about the output levels produced on a farm (or agricultural sector) x^0 , than information on the cost of producing them. No doubt, when deciding to produce a given amount x^0 , entrepreneurs are well aware of all costs they will incur (such as costs associated with technologies, environmental conditions, possible hazards and so on), therefore the selected production portfolio is the result of decision-making whereby farmers or their families make decisions that may vary between individual farms. The observed output levels are therefore the result of complex decisions, the cost of which are known to the entrepreneurs, but can hardly be measured by outside observers.

Heckelei (1997) showed that the addition of the calibration constraints will force the optimal solution of the LP model to reproduce exactly the observed base year activity levels x^0 , given that the specified resource constraints allow for this solution. "Exactly" is accurately understood to mean within the range of the positive perturbations of the calibration constraints, ε , which are included to guarantee that all binding resource constraints of the model remain binding here. Arfini and Paris (1995) are of the opinion that the specification of the model as described in (2) is often the best possible given the available information. They also point out that the first step is often called the estimation (calibration) step. The goal of the calibration is to "estimate" the cost function that is not measurable directly as well as to "calibrate" the model so that it reproduces the results observed in a given base period. The PMP method involves all the characteristic components of a well-made empirical analysis, consisting of two discrete phases of estimate (or calibration) and prediction. In particular, the PMP calibration phase is designed to estimate a "pseudo-cost" function that replaces the hidden and unobservable cost function used by the entrepreneurs. The prediction phase (Phase 2) uses the calibrated model to generate responses in the endogenous variables induced by the variation of some relevant parameters, assimilated to the exogenous variables of econometric models.

The vector x can be divided into two subsets, an ((n-m)'1) vector of preferable activities, x^p , which are constrained by the calibration constraints, and a (m '1) vector of marginal activities, x^m , which are constrained by the resource constraints. To simplify notation without loss of generality, we assume that all elements in x^0 are nonzero and all resource constraints are binding. Then the Kuhn-Tucker conditions imply that

(3) $\lambda^p = p^p - c^p - A^{p'}\pi$

(4) $\lambda^m = [\,0\,]$

(5) $\pi = (A^{m'})^{-1}(p^m - c^m)$

where the superscript p and m indicate subsets of original vectors and matrices corresponding to preferable and marginal activities, respectively. The dual values for the calibration constraints are zero for marginal activities (λ^m) and equal to the difference between price and marginal cost for preferable activities (λ^p), the latter being the sum of variable cost per activity unit (c) and the marginal cost of fixed resources ($A^{p'}\pi$). The dual values of the resource constraints (π) only depend on objective function entries and coefficients of marginal activities.

This step is characterised by a constraint set that gives the model its "positive" character, in fact it reflects an actual occurrence, resulting from the decisions concerning his production plans. In particular, it is assumed that the output x never exceeds the actual one x^0 . This makes it possible to highlight the shadow prices λ for each process. The shadow prices thus obtained are indicative of the "opportunity cost" suffered by farmers for giving up additional output and allowing estimating total variable costs in the second phase of the model. The first model therefore only maximises the saleable gross output that is subject to technical constraints (matrix A) and to the actual observed outputs x^0 (Arfini and Paris, 1995).

In Step 2 the dual values of the calibration constraints of the preferable activities (λ^p) are used to specify a non-linear objective function such that the marginal cost of the preferable activities are equal to their respective prices at the base year activity levels x^0 . Howitt (1995) pointed out that if the implied variable cost function has the right curvature (convex) the solution to the resulting problem would be a boundary point, which is the combination of binding constraints and first order conditions.

For reasons of computational simplicity and lacking strong arguments for other type of functions, a quadratic cost function is usually employed. The general version of this variable cost function to be specified is then

(6) $Cv = d'x + 0,5x'Qx$

with

d = (n '1) vector of parameters associated with the linear term and

Q = (n 'n) symmetric, positive semi-definite matrix of parameters associated with the quadratic term.

The parameters needs to be specified such that

(7) $\delta C^v(x^0)/\delta x = d + Qx^0 = c + \lambda$

The problem of specifying n+n(n+1)/2 parameters on the basis of 2n pieces of information is usually solved by letting d=c and setting all off-diagonal elements Q to 0 (Heckelei, 1997). Building a quadratic programming sub-model requires that an additional parameter be defined, which is referred to as q_{ii} . This denotes the ratio of the shadow price (γ) of each calibration constraint to the corresponding actual output x^0 . This parameter enters the model in a diagonal matrix having *n x n* dimensions, called matrix Q (Arfini and Paris, 1995).

The n diagonal elements of Q, q_{ii}, can then be calculated as

(8) $q_{ii} = \gamma^i/x^0_i$ for all i = 1,....,n

It is easily verified that the resulting variable cost function satisfied condition (7).

The final non-linear programming problem that is exactly calibrated to base-year activity levels is

$MaxZ = p'x - c'x - 0.5x'Qx$

(9) subjected to

$Ax \leq b$ $[\pi]$

$x \geq [0]$

It should be noted that the dual values of the resource constraints in model (9) do not differ from the ones in model (2). The objective function coefficients associated with the linear x^m terms did not change (p^m, c^m) and because of (4) and (8) the corresponding diagonal entries of the Q matrix are zero. Consequently, equation (5) remains unchanged.

Arfini and Paris (1995) pointed out that the distinguishing element of this sub-model is the assessment of variable total cost through the expression $0.5x'Qx$, this being the integral of the farm variable cost ($\gamma.x^0$). Moreover, it is apparent that "positive" (calibration) constraints are lacking, thus leaving the model free to choose the best production combination albeit subject to the assumed resource constraints, in accordance to economic convenience criteria only.

APPENDIX C

Table C.1: Water restrictions - objective function parameters and agricultural land use

Paramater	Base	10%	20%	30%	40%	Base	10%	20%	30%	40%
Objective value (million Rand)	7822	7442	6997	6361	5641	7846	7679	7274	6697	5863
Consumer surplus (million Rand)	5097	4339	3551	2712	1977	5098	4883	3930	3010	2172
Total NDI (million Rand)	611	518	498	455	410	634	566	557	549	416
NDI per m^3 of water (Rand)	10.45	11	10.96	10.74	10.39	8.907	11.36	11.38	11.33	10.47
Land use										
LT-Optimum (ha)	8107	2891	3158	2449	2043	11425	5208	5073	4689	2521
LT-Deficit (ha)	763	2722	2089	2108	2214	154	1148	1247	1640	1647
LT-Supplemental (ha)	3234	6443	6449	6644	6309	526	5748	5784	5773	6288
Total long-term (ha)	12104	12056	11697	11201	10566	12104	12104	12104	12102	10457
Vegetables-optimum (ha)	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432
Total area irrigated (ha)	13536	13488	13128	12633	11998	13536	13536	13535	13534	11888

Table C.2: Water restrictions - water supply and demand balances

Agricultural water use (Million m^3)	Base	10%	20%	30%	40%	Base	10%	20%	30%	40%
Total summer water allocation	44	39	35	31	26	44	39	35	31	26
Summer allocation utilised	41	31	29	27	24	42	39	35	31	26
Total winter water allocation	27	27	27	27	27	27	27	27	27	27
Winter allocation utilised	12	10	10	10	9	25	25	25	25	21
Winter allocation utilised to fill farm dam	3	3	3	3	3	3	2	2	3	3
Winter allocation utilised for irrigation	9	7	7	6	6	22	23	23	22	18
Farm dam water storage capacity	7	7	7	7	7	7	7	7	7	7
Farm dam water utilised	16	16	16	16	16	16	15	15	16	16
Obtained through permanent trade	0	0	0	0	0	0	0	0	0	0
Obtained through tempory trade	0	0	0	0	0	7	1	2	4	4
Permanent sold to the urban sector	0	0	0	0	0	0	0	0	0	0
Temporary lease to the other users	0	0	0	0	0	14	20	17	15	18
Total water usage	65	54	52	49	46	74	58	57	57	46
Urban water use (Million m^3)										
Total allocation – Theewaters	125	113	100	88	75	125	113	100	88	75
Allocation bought from Theewaters	125	113	100	88	75	125	113	100	88	75
Obtained through permanent trade	0	0	0	0	0	0	0	0	0	0
Obtained through temporary trade	0	0	0	0	0	6	19	15	12	14
Permanent sold to the agric sector	0	0	0	0	0	0	0	0	0	0
Temporary lease to the agric sector	0	0	0	0	0	0	0	0	0	0
Other dams	185	167	148	130	111	179	167	148	130	111
Possible sources	0	0	0	0	0	0	0	0	0	0
Total m^3 used-all sources	310	279	248	217	186	310	298	263	229	200
Total trade (urban plus agric)	0	0	0	0	0	21	21	19	20	22
Average urban water price (R/m^3)	7.6	10.6	13.6	16.9	20.9	7.6	8.7	12.1	15.8	19.5

Table C.3: Water restrictions - marginal value of water

Present allocation value (R/m3)	Base	10%	20%	30%	40%	Base	10%	20%	30%	40%
Urban	10.1	12.5	17.0	24.6	31.1	1.4	10.0	14.8	21.4	35.4
Median agricultural value	1.6	0.0	0.0	1.4	12.8	0.3	8.6	13.4	20.3	34.2
Maximum agricultural value	20.2	19.3	19.7	19.4	19.4	0.3	8.9	13.7	20.4	34.4
Minimum agricultural value	0.0	0.0	0.0	0.0	0.0	0.0	7.4	12.4	19.0	32.9

Table C.4: Water restrictions - crop combinations

Long term crops	Base	10%	20%	30%	40%	Base	10%	20%	30%	40%
IRwine	3034	3034	3021	2848	2595	3034	3035	3035	3035	2438
IWwine	3864	3864	3767	3766	3802	3865	3865	3864	3864	3501
ITable	2837	2807	2601	2316	1995	2837	2837	2837	2836	2474
IPlum	566.8	566.7	566.7	566.6	566.6	566.8	566.8	566.7	566.6	478.7
ISoftc	518.4	513.8	507	489.2	420.3	518.5	518.4	518.4	518.4	313.6
ICitr	0	62.75	54.45	54.46	0	0	0	0	0	0
ILem	194.3	131.5	139.8	72.27	194.3	194.3	194.3	194.3	194.3	182
IOliv	368.2	368.2	368.1	368.1	357.1	368.2	368.2	368.2	368.1	349.5
IPear	295.5	282.4	247.4	295.5	210.8	295.5	295.5	295.5	295.5	295.5
IPeach	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2
INect	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2
IAppr	11.62	11.62	11.62	11.62	11.62	11.62	11.62	11.62	11.62	11.62
IGuav	71.11	71.12	71.11	71.11	71.11	71.14	71.11	71.11	71.11	71.11
ILucer	47.79	47.79	47.79	47.78	47.78	47.79	47.77	47.77	47.77	47.77
Total	12104	12056	11697	11201	10566	12104	12104	12104	12102	10457
Vegetable irrigation crops										
ICauli	254.3	11.25	0	0	0	238.7	0	0	0	0
ICabaS	0	0	0	0	0	0	0	0	0	0
ICabaW	254.3	335.4	470.7	461.7	466.6	238.7	238.6	477.2	477.2	477.2
IBrocS	0	324.2	470.7	461.7	466.6	0	238.6	477.2	477.2	477.2
IBrocW	0	78.51	286	331.1	193.1	0	0	0	0	477.2
ICarrS	0	0	0	0	0	0	0	0	0	0
ICarrW	31.29	115	178.1	115	262.8	0	0	477.2	477.2	0
ITom	0	0	0	0	0	0	0	0	0	0
IGrenbS	0	0	0	0	0	0	0	0	0	0
IGrenbW	0	0	0	0	0	0	0	0	0	0
IGrenpS	0	0	0	0	0	0	0	0	0	0
IGrenpW	0	0	0	0	0	0	0	0	0	0
ICucm	0	0	0	0	0	0	0	0	0	0
ILettuS	223	141.9	6.6	15.59	10.7	238.7	238.7	0	0	0
ILettuW	223	141.9	6.6	15.59	10.7	238.7	238.7	0	0	0
IBeetrS	0	0	0	0	0	0	0	0	0	0
IBeetrW	223	141.9	6.6	15.59	10.7	238.7	238.6	0	0	0
ISwpot	223	141.9	6.6	15.59	10.7	238.7	238.6	0	0	0
Total vegetable area	**1432**	**1432**	**1432**	**1432**	**1432**	**1432**	**1432**	**1432**	**1432**	**1432**
Dryland crops (ha)										
DRwin	397.9	397.9	397.9	397.9	397.9	397.9	397.9	397.9	397.9	397.9
DWwin	474.1	474.1	474.1	474.1	474.1	474.1	474.1	474.1	474.1	474.1
DWhea	7809	7809	7808	7808	7808	7809	7809	7809	7809	7808
DCanol	421	421	421	421	421	421	421	421	421	420.9
DKorog	11	11	11	11	11	11	11	11	11	11
DOats	1169	1169	1169	1169	1169	1169	1169	1169	1169	1169
DPast	1264	1264	1264	1264	1264	1264	1264	1264	1264	1264
DLup	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3
DBarl	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32
DLucer	2071	2071	2071	2071	2071	2071	2071	2071	2071	2071
DPotat	32.71	32.71	32.71	32.71	32.71	32.71	32.71	32.71	32.71	32.71
DOlive	90.02	90.02	90.02	90.02	90.02	90.02	90.02	90.02	90.02	90.02
Total area under dryland crops	**13861**	**13862**	**13861**	**13860**	**13860**	**13861**	**13861**	**13861**	**13861**	**13861**

Table C.5: Urban use growth – objective function parameters and land use

Item	No trade					Trade				
Parameter	**Base**	**20%**	**40%**	**60%**	**80%**	**Base**	**20%**	**40%**	**60%**	**80%**
Objective function (million Rand)	7803	9100	10620	12413	13439	7840	9170	10706	12516	13576
Consumer surplus (million Rand)	5098	6118	7341	8809	9690	5098	6118	7341	8809	9690
Total NDI (million Rand)	638	638	638	638	638	630	626	624	624	619
NDI per m^3 of water per region (Rand)	9.0	9.0	9.0	9.0	9.0	8.8	8.7	8.9	8.9	9.1
Land use										
LT - Optimum (ha)	11516	11516	11516	11516	11516	11530	11785	10611	10687	10066
LT – Deficit (ha)	62	62	62	62	62	49	62	967	967	1006
LT - Supplemental (ha)	526	526	526	526	526	526	257	526	451	1032
Total long-term (ha)	12104	12104	12104	12104	12104	12104	12104	12104	12104	12104
Vegetable-optimum irrigation (ha)	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432
Total area irrigated (ha)	13536	13536	13536	13536	13536	13536	13536	13536	13536	13536

Table C.6: Urban use growth - water supply and demand balances

Item	No trade					Trade				
AgriculturAL water use (Million m^3)	**Base**	**20%**	**40%**	**60%**	**80%**	**Base**	**20%**	**40%**	**60%**	**80%**
Total summer water allocation	75	75	75	75	75	75	75	75	75	75
Summer allocation utilised	48	48	48	48	48	72	75	75	75	75
Total winter water allocation	28	28	28	28	28	28	28	28	28	28
Winter allocation utilised	13	13	13	13	13	27	28	27	27	27
Winter allocation utilised to fill farm dam	3	3	3	3	3	3	3	3	3	2
Winter allocation utilised for irrigation	9	9	9	9	9	23	24	24	23	25
Farm dam water storage capacity	17	17	17	17	17	17	17	17	17	17
Farm dam water utilised	16	16	16	16	16	16	16	16	16	15
Obtained through permanent trade	0	0	0	0	0	0	0	0	0	0
Obtained through tempory trade	0	0	0	0	0	0	0	0	0	0
Permanent sold to the urban sector	0	0	0	0	0	0	0	0	0	0
Temporary lease to the other users	0	0	0	0	0	38	41	42	42	44
Total water usage	74	74	74	74	74	74	74	72	73	71
Urban water use (million m^3)										
Theewaters	93	93	93	93	93	93	93	93	93	93
Trade	0	0	0	0	0	38	41	42	42	44
Other dams	185	185	185	185	185	179	185	185	185	185
Possible sources	32	94	168	258	311	0	53	126	216	268
Total urban water supply	310	372	446	536	589	310	372	446	536	589
Total trade (urban plus agric)	0	0	0	0	0	38	41	42	42	44
Average urban price (Rand per m^3)	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8

Table C.7: Urban growth restrictions - marginal value of water

Item	No trade					Trade				
Present allocation value (R/m^3)	**Base**	**20%**	**40%**	**60%**	**80%**	**Base**	**20%**	**40%**	**60%**	**80%**
Urban	2.7	3.4	3.7	4.8	4.8	1.4	2.7	3.4	3.7	4.8
Median agricultural value	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.0	2.4	3.4
Maximum value	13.6	13.6	13.6	13.6	13.6	0.3	1.6	2.0	2.4	3.4
Minimum value	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	1.0	2.1

Table C.8: Urban growth - crop combinations

		No trade					Trade			
Long term crops (ha)	**Base**	**20%**	**40%**	**60%**	**80%**	**Base**	**20%**	**40%**	**60%**	**80%**
IRwine	3034	3034	3034	3034	3034	3034	3035	3035	3035	3034
IWwine	3865	3865	3865	3865	3865	3865	3865	3865	3865	3865
ITable	2837	2837	2837	2837	2837	2837	2837	2837	2837	2837
IPlum	566.8	566.8	566.8	566.8	566.8	566.8	566.8	566.8	566.8	566.8
ISoftc	518.5	518.5	518.5	518.5	518.5	518.5	518.4	518.4	518.4	518.4
ICitr	0	0	0	0	0	0	0	0	0	0
ILem	194.3	194.3	194.3	194.3	194.3	194.3	194.3	194.3	194.3	194.3
IOliv	368.2	368.2	368.2	368.2	368.2	368.2	368.2	368.2	368.2	368.2
IPear	295.5	295.5	295.5	295.5	295.5	295.5	295.5	295.5	295.5	295.5
IPeach	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2
INect	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2	147.2
IAppr	11.62	11.62	11.62	11.62	11.62	11.62	11.62	11.62	11.62	11.62
IGuav	71.14	71.14	71.14	71.14	71.14	71.14	71.14	71.14	71.14	71.11
ILucer	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.79	47.78	47.77
Total long-term crops	**12104**	**12104**	**12104**	**12104**	**12104**	**12105**	**12104**	**12104**	**12104**	**12104**
Vegetable irrigation crops (ha)										
ICauli	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7
ICabaS	0	0	0	0	0	0	0	0	0	0
ICabaW	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.6	238.6
ILettuS	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7
ILettuW	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7
IBeetrS	0	0	0	0	0	0	0	0	0	0
IBeetrW	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.7
ISwpot	238.7	238.7	238.7	238.7	238.7	238.7	238.7	238.6	238.6	238.6
IPepp	0	0	0	0	0	0	0	0	0	0
Total vegetable area (ha)	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432
Dryland crops (ha)										
DRwin	397.9	397.9	397.9	397.9	397.9	397.9	397.9	397.9	397.9	397.9
DWwin	474.1	474.1	474.1	474.1	474.1	474.1	474.1	474.1	474.1	474.1
DWhea	7809	7809	7809	7809	7809	7809	7809	7809	7809	7809
DCanol	421	421	421	421	421	421	421	421	421	421
DKorog	11	11	11	11	11	11	11	11	11	11
DOats	1169	1169	1169	1169	1169	1169	1169	1169	1169	1169
DPast	1264	1264	1264	1264	1264	1264	1264	1264	1264	1264
DLup	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3
DBarl	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32	18.32
DLucer	2071	2071	2071	2071	2071	2071	2071	2071	2071	2071
DPotat	32.71	32.71	32.71	32.71	32.71	32.71	32.71	32.71	32.71	32.71
DOlive	90.02	90.02	90.02	90.02	90.02	90.02	90.02	90.02	90.02	90.02
Total area under dryland crops	13861	13861	13861	13861	13861	13861	13861	13861	13861	13861

APPENDIX D

Table D.1: Transaction costs scenarios - objective function and land use

Parameter	0.0	0.6	1.0	5.0	5.6	5.8	6.2
Objective function (million Rand)	9328	9318	9312	9219	9197	9191	9180
Consumer surplus (million Rand)	6118	6118	6118	6118	6118	6118	6118
Total NDI (million Rand)	789	785	785	773	774	774	773
NDI per m^3 of water (Rand)	9.0	8.8	8.7	8.3	8.2	8.2	8.2
Land Use	0.0	0.6	1.0	5.0	5.6	5.8	6.2
LT-Optimum (ha)	11875	11981	12352	12747	12747	12747	12759
LT-Deficit (ha)	695	588	567	177	177	177	166
LT-Supplemental (ha)	848	848	395	394	394	394	394
Total long-term (ha)	13418	13418	13314	13319	13319	13319	13319
Vegetables-optimum (ha)	1520	1520	1520	1520	1520	1520	1520
Total area irrigated (ha)	14938	14938	14834	14839	14839	14839	14839

Table D.2: Transaction costs scenarios - water supply and demand balances

Agricultural water use (million m^3)	**0.0**	**0.6**	**1.0**	**5.0**	**5.6**	**5.8**	**6.2**
Total summer water allocation	74.8	74.8	74.8	74.8	74.8	74.8	74.8
Summer allocation utilised	74.8	74.8	74.8	73.6	59.8	53.2	53.2
Total winter water allocation	28.2	28.2	28.2	28.2	28.2	28.2	28.2
Winter allocation utilised	27.9	27.9	27.9	27.6	27.6	27.6	24.3
Winter allocation utilised to fill farm dam	2.3	2.9	2.8	2.9	2.9	3.4	3.4
Winter allocation utilised for irrigation	25.6	25.1	25.1	24.7	24.6	24.2	20.9
Farm dam water storage capacity	17.2	17.2	17.2	17.2	17.2	17.2	17.2
Farm dam water utilised	15.1	15.7	15.7	15.8	15.8	16.2	16.2
Obtained through permanent trade	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Obtained through temporary trade	0.8	0.8	1.7	1.7	1.8	1.8	1.8
Permanent sold to the urban sector	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Temporary lease to the other users	37.1	37.0	37.0	35.1	20.8	14.2	1.8
Total water usage	79.2	79.4	80.1	80.7	81.2	81.2	81.2
Urban water use (million m^3)							
Total allocation - Theewaters	93.0	93.0	93.0	93.0	93.0	93.0	93.0
Theewaters	93.0	93.0	93.0	93.0	93.0	93.0	93.0
Trade	36.4	36.2	35.3	33.4	19.0	12.4	0.0
Other dams	185.0	185.0	185.0	185.0	185.0	185.0	185.0
Possible sources	57.6	57.8	58.8	60.6	75.0	81.6	94.0
Total m^3 used-all sources	372.0	372.0	372.0	372.0	372.0	372.0	372.0
Total trade (urban plus agric)	38.1	37.9	38.8	37.0	22.6	16.0	3.6
Average urban price (R/m^3)	7.8	7.8	7.8	7.8	7.8	7.8	7.8

Table D.3: Transaction costs scenarios - marginal value of water

Present allocation value (R/m^3)	**0.0**	**0.6**	**1.0**	**5.0**	**5.6**	**5.8**	**6.2**
Urban	3.1	3.1	3.1	3.1	3.3	3.4	3.4
Median agricultural value	1.8	1.7	1.6	0.2	0.0	0.0	0.0
Maximum agricultural value	2.0	2.0	2.0	1.0	0.7	0.7	0.4
Minimum agricultural value	0.8	0.7	0.6	0.0	0.0	0.0	0.0

Table D.4: Transaction costs scenarios – crop combinations

Long term crops	0.0	0.6	1.0	5.0	5.6	5.8	6.2
IRwine	3634	3634	3530	3530	3530	3530	3530
IWwine	3970	3970	3970	3940	3940	3940	3940
ITable	3545	3545	3545	3545	3545	3545	3545
IPlum	708	708	708	708	708	708	708
ISoftc	393	393	393	394	394	394	394
ICitr	0	0	0	0	0	0	0
ILem	151	151	151	154	154	154	154
IOliv	430	430	430	430	430	430	430
IPear	222	222	222	222	222	222	222
IPeach	124	124	124	154	154	154	154
INect	115	115	115	115	115	115	115
IAppr	9	9	9	9	9	9	9
IGuav	57	57	57	57	57	57	57
Ilucer	60	60	60	60	60	60	60
Total area under long-term crops	**13418**	**13418**	**13314**	**13319**	**13319**	**13319**	**13319**
Vegetable irrigation crops							
Icauli	229	229	229	228	142	142	142
IcabaS	0	0	0	0	0	0	0
IcabaW	3	3	3	2	2	2	2
ILettuS	355	355	355	356	356	356	356
ILettuW	224	224	224	223	223	223	223
IBeetrS	5	5	5	5	5	5	5
IBeetrW	355	355	355	356	356	356	356
ISpasp	0	0	0	0	0	0	0
IWatle	216	216	216	216	216	216	216
ISwetc	0	0	0	0	0	0	0
IWmze	0	0	0	0	0	0	0
IPump	0	0	0	0	0	0	0
IButter	0	0	0	0	0	0	0
ISqua	0	0	0	0	0	0	0
IPotat	0	0	0	0	0	0	0
ISwpot	134	134	134	135	221	221	221
IPepp	0	0	0	0	0	0	0
Total vegetable crops	**1520**	**1520**	**1520**	**1520**	**1520**	**1520**	**1520**
Dryland crops (ha)							
DRwin	497	497	497	497	497	497	497
DWwin	593	593	593	593	593	593	593
DWhea	9561	9561	9561	9561	9561	9561	9561
DCanol	526	526	526	526	526	526	526
DKorog	8	8	8	8	8	8	8
DOats	1448	1448	1448	1448	1448	1448	1448
DPast	979	979	979	979	979	979	979
DLup	130	130	130	130	130	130	130
DBarl	23	23	23	23	23	23	23
DLucer	1553	1553	1553	1553	1553	1553	1553
DPotat	41	41	41	41	41	41	41
DOlive	113	113	113	113	113	113	113
Total area under dryland crops	**15472**	**15472**	**15472**	**15472**	**15472**	**15472**	**15472**