DISSERTATION

THE VALUE OF WATER IN THE FISH-SUNDAYS SCHEME OF SOUTH AFRICA

Submitted by

Beatrice I. Conradie

Department of Agricultural and Resource Economics

In partial fulfillment of the requirements
For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring 2002

UMI Number: 3053416

UMI Microform 3053416

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February 1, 2002

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Committee on Graduate Work

Co-Advisor

Advisor

Head of Department

ABSTRACT OF DISSERTATION

THE VALUE OF WATER
IN THE FISH-SUNDAYS SCHEME OF SOUTH AFRICA

This study analyses the economic efficiency of water allocation on the Fish-Sundays scheme in the Eastern Cape Province of South Africa. The objective is to develop a basin-wide model of water use that calculates total and marginal water value. Estimates of total value are used to confirm financial feasibility while marginal values measure the efficiency of current allocation as well as gains from reallocation. A linear programming model shadow prices commercial irrigation, which controls 97 percent of available water on the scheme as a first attempt to value an ecological reserve, irrigation equity and municipal demand.

Total water value is defined as residual farm profit after all fixed resources have been remunerated at their opportunity cost. Risk is introduced through MOTAD, which penalises the objective function by an exogenous weighting according to risk preference. Accounting for risk reduces total and marginal water values, which are also sensitive to the value of crops and input prices.

Total water value for the scheme is estimated to be R27 million in 1999 Rand ($\pm$ \$2.24 million) and irrigation shadow prices range from zero to R0.2115/m^3 ($\pm$ \$0.0176/m^3). Results indicate that 77 million m^3/year can be transferred out of irrigation at zero opportunity cost. Two thirds of the current allocation to irrigation can be

bid away at a price of R0.0352/m^3 ($\pm$ \$0.003/m^3). Thus equity objectives can be satisfied at zero or very low opportunity cost to commercial irrigation.

The typical model of water value relies on a vast array of assumptions that all influence final values. While orders of magnitude and directions of reallocation are therefore meaningful, one should not attach too much meaning to any particular result. Administered prices are too data intensive to be practical. Water markets represent a more reliable and cost effective institutions to derive subjective willingness to pay.

Beatrice Isabel Conradie
Department of Agriculture
& Resource Economics
Colorado State University
Fort Collins, CO80523
Spring 2002

ACKNOWLEDGEMENTS

Apart from thanking my graduate committee – Drs. Dana Hoag, Marshall Frasier, Tim Gates and Jerry Eckert – for their wise and gentle guidance, I would like to acknowledge the generous financial support of the Water Research Commission of South Africa. Special thanks to Drs. Gerhard Backeberg and Lieb Nieuwoudt as well as the rest of the Steering Committee for their supervision during my fieldwork in South Africa.

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CHAPTER 1: INTRODUCTION

Economics has a long history of informing water allocation decisions in many arid parts of the world. At the turn of the previous century the discipline was called upon to justify infrastructure investments by means of benefit-cost analysis in South Africa and elsewhere (Secretary of Water Affairs 1962; Backeberg, 1984; Burness et al, 1983). The American West and Western Australia provide useful comparisons for the South African experience, since both countries have a similar irrigation history and water endowment to South Africa.

Since the mid 1980s the emphasis on increasing supply has been replaced by a strategy of demand management (Howe, 1985; Renwick and Archibald, 1998; Stephenson, 1999). Preoccupation with benefit-cost ratios greater than unity is exchanged for a focus on marginal value and putting a scarce resource to its best possible use. In South Africa, the National Water Act (Act 36 of 1998) formalises several demand management strategies including administered prices. This report, as most other economic studies, focuses on price as the chief tool of demand management, but also calculates total value in the tradition of benefit-cost analysis. It is part of a growing body of South African literature that tests analytical frameworks to value water and identify optimal pricing policies.

The overall objective here is to develop a realistic model of basin-wide water use to examine optimal resource allocation. The model focuses on commercial irrigation, which claims 97 percent of water in the basin (Backeberg et al, 1996; Basson, 1999). An ecological reserve, municipal demand and irrigation equity tribal communities are also considered. Policy scenarios include transfers among different classes of irrigators, reallocation across irrigation regions as well as tradeoffs between irrigators and other groups. The model also calculates the opportunity cost of inter-basin transfers.

The National Water Act (Act 36 of 1998) declares an ecological reserve and basic water service for all South Africans that reduces the supply of exploitable water. The Act also states the objective of "redressing past racial discrimination", which is interpreted here as priority access for black communities with riparian claims. Furthermore, municipal use has a tradition of high levels of assurance in South Africa that effectively gives it a senior claim. Thus categories other than commercial irrigation are modelled as a reserve than restricts supplies to commercial irrigation.

The allocation question pertains to trade-offs between groups, and requires a comparison of marginal values to make conclusions about allocative efficiency. Instead of estimating a marginal value for the reserve, the model calculates the opportunity cost to commercial irrigation on water released. Irrigation opportunity cost is interpreted as a lower bound of value for the other groups. This way society selects appropriate equity objectives, and the economic model calculates the cost of these policies, if any.

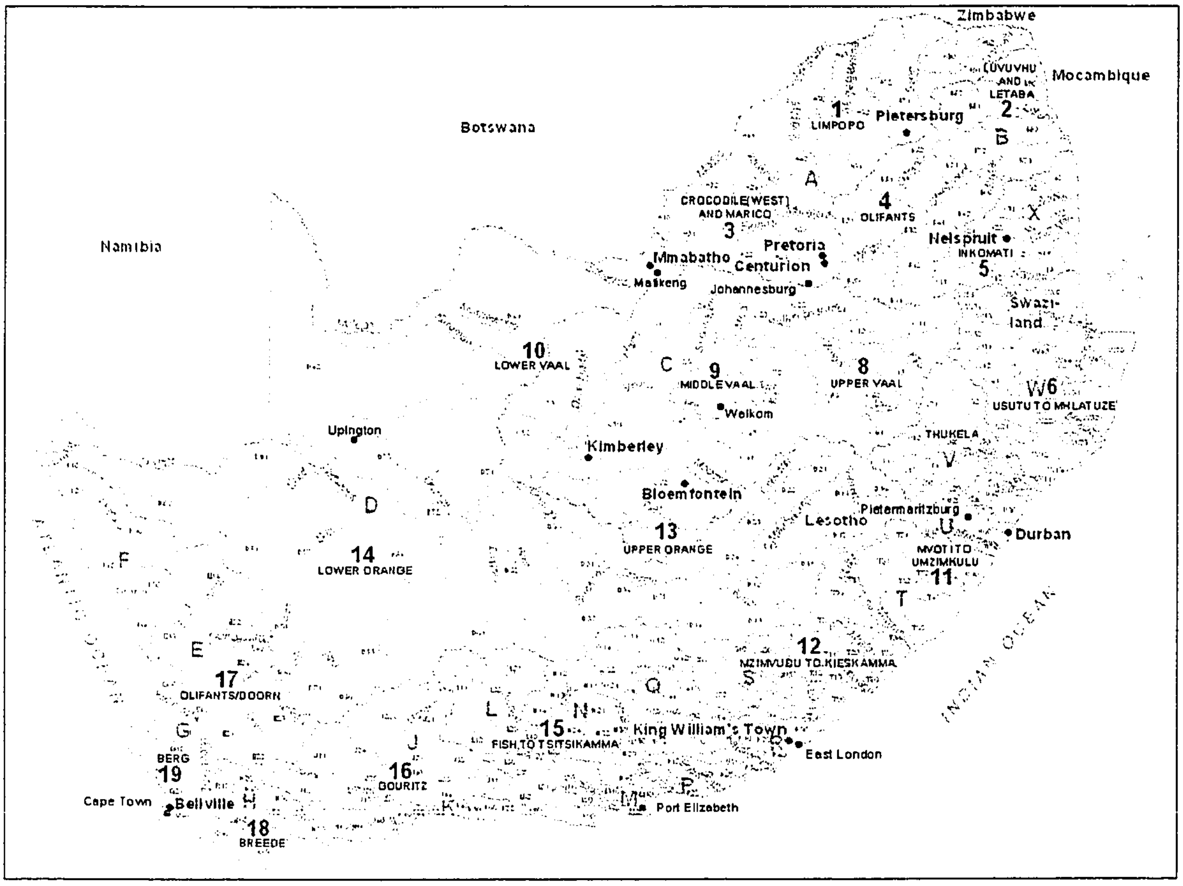


Figure 1.1: Map of South Africa

The setting of the present study, given in the map above, is the Fish-Sundays transfer scheme in the Eastern Cape Province of South Africa. As shown in figure 1.2 the scheme comprises the upper two-thirds of the Great Fish River and the last 100 kilometres of the adjacent Sundays River basin. The scheme is supplied by an inter-basin transfer of 560 million m^3/year from Gariep Dam on the Orange River. In the last five years the Orange River contributed between 65 and 95 percent of the Fish-Sundays scheme's water.

Chapter 2 reviews the water valuation and pricing literature and concludes that if is possible to demonstrate a value differential at the margin across user categories, reallocation enhances total welfare. This argument is presented *inter alia* by Michelsen and Young (1993), Booker and Young (1994), Taylor and Young (1995) and Turner and Perry (1997).

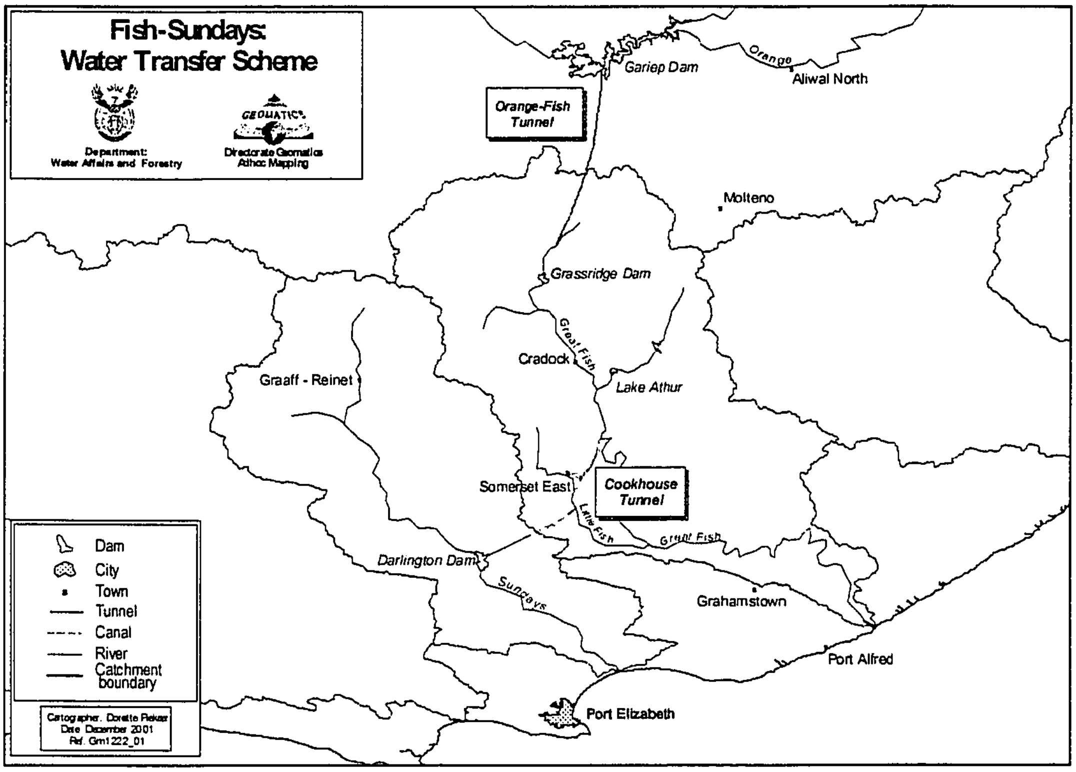


Figure 1.2: The Fish-Sundays scheme

The rest of the study implements a proposed five-step procedure for valuing water and examining reallocation. Chapter 3 describes the first analytical step, which involves reviewing a water balance for the scheme. The second step is to derive demand curves for each important user category. Municipal demand is presented in Chapter 4, demand for commercial irrigation is derived in Chapter 5 and 6, and traditional small-scale irrigation requirements are discussed in Chapter 7. The third step then calls for sector specific water values. Since water values are the integral of the sector-specific demand functions they are reported as part of Chapters 4 to 7.

Chapter 8 concludes and reflects on the study. It first integrates the sector-specific models into a single value for water in the Fish-Sundays scheme, which is compared to operations and maintenance cost in order to complete step 4 of the valuation procedure. Chapter 8 also accomplishes step 5, by exploring the reallocation scenarios listed before. It presents evidence that reallocation can double the total value of water compared to the current allocation. Finally, the chapter offers conclusions about the feasibility of the analytical framework itself.

CHAPTER 2: THE ECONOMICS OF DEMAND MANAGEMENT

2.1. Introduction

The popularity of demand management rests on the claim that reallocation will supply the cheapest source of water in future (Howe, 1985; Brooks, 1994). The only feasible alternative is to continue building storage facilities and interbasin transfers, but further opportunities may not exist in a particular basin. If such options are available, the rules to optimally expand capacity are mentioned by Sampath (1992) and discussed in detail by Church and Ware (2000) but are beyond the scope of the present study.

There are three objectives with the literature review:

1. To examine the theoretical arguments that underpin demand management
2. To review models of sector-specific demand and reallocation
3. To identify data sources and analyses pertaining to the Fish-Sundays scheme

This chapter first evaluates water in a consumption setting and then studies water as a factor of production. In both cases the theory is followed by a review of models. The environmental reserve is also discussed in the demand management context. The chapter closes with conclusions on modelling of water use in the Fish-Sundays basin.

2.2. Demand management in a consumption setting

Residential demand is exceptional insofar as it is the only category where water is consumed directly, and is not a factor of production. For the most part, residential water is sold by volume and hence competes directly with all other items in the household budget. Consumer choice is modelled as utility maximisation, which assumes local non-satiation and convex, complete, reflexive and transitive preferences to permit a unique solution to the household's optimisation problem. The result is the familiar downward sloping demand function that summarises a consumer's quantity-price response and reveals total and marginal value of a particular level of use. The demand curve also forms the basis on which the efficiency of allocation among potential consumers is judged. This section examines the assumption that water behaves like any other consumer good and reviews techniques for estimating residential demand.

2.2.1. Residential use and the law of demand

If one accepts that demand management will eventually be inevitable and even affect residential use, it raises the question of which instrument is the most suitable to reduce the level of household demand. Three broad groups of opinions emerge, namely, those in favour of non-market intervention, regulation economists who believe that price alone can regulate allocation, and institutional economists who emphasise rights.

In practice municipalities employ a variety of price and non-price demand management measures to reduce quantity demanded. These include variable pressure, rationing in times of drought through, for example, restricted garden watering, penalties for non-compliance, stepped tariffs, subsidies of water-saving technology, appeals and informative billing (Renwick and Archibald, 1998; Stephenson, 1999).

A key question is if consumer behaviour is primarily changed through "other measures" or in response to price increases (Randall, 1981; Agthe and Billings, 1996; Stephenson, 1999). The answer depends on whether water is believed to be commodity, or a merit good that cannot be efficiently allocated by the market (Schutte and Pretorius, 1997; McMaster and Mackay, 1998).

Economists generally take the position that water is a commodity and hence that demand can be sufficiently managed through price. Espey et al (1997) published a survey of 124 estimates of price elasticity of demand for residential water, which provides ample evidence that consumers respond to water price changes. A price elasticity measures how much of the variation in quantity demanded is due to price changes, and if price elasticity is negative it confirms the law of demand which claims that if price goes up, consumers want less.

It can be argued that the Espey et al (1997) evidence deals with luxury water use, and does not necessarily extend to basic-needs water. Quantity demanded is a function of willingness-to-pay *and* ability-to-pay and while consumers may be willing to pay an infinite amount for basic-needs water, the poor's inability to pay may exclude them from the resource (McMaster and Mackay, 1998). Schur (1994) suggests that the poor should not have to pay for water simply because it is a scarce commodity.

Present legislation supports the basic-needs position. The National Water Act (Act 36 of 1998) defines a basic-needs reserve that "provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene". The Water Services Act (Act 108 of 1997) defines a basic water supply as 25 litre per person per day.

The basic-needs position is not consistent with demand management, and the government cannot achieve two policy objectives with the same instrument. The equity debate is not unimportant, but is not the focus of the present study. Moreover, empirical evidence suggests that the poor are willing to pay about double the generally accepted 5 percent of annual income for water.

In Kenya Rogerson (1996) found that the average annual expenditure on water is $30 per capita (1989 dollars), which is equivalent to 9 percent of average annual income. Morris and Parry-Jones (1999) report that the Jinja community of Uganda on average spends 10 percent of disposable income on water, even though the community has easy access to Lake Victoria's water. In a study of drinking water in Djakarta Rogerson (1996) found that the price of safe drinking water sold by street vendors is up to 50 times higher than the price of piped water and that about a third of Djakarta's 8 million inhabitants buys drinking water from vendors. These examples illustrate that even poor people are willing to pay for water, and this willingness to pay indicates the opportunity for efficient allocation through price.

2.2.2. Estimating municipal and residential demand

Time-series econometrics is the standard technique to derive residential demand (Gibbons, 1986), but Wilchfort and Lund's 1997 paper provides at least one example of estimating municipal demand with a linear programming model. Econometric models rely on the assumption that water is an ordinary household good with a well-known price. The typical model explains the variation in quantity demanded through the change in price and exogenous variables like climate or income.

Structural breaks are expected for climate, including droughts, for average age and composition of household, size of house, the presence of gardens and swimming pools, and potentially for cultural differences. Table 2.1 below summarises the shift variables used in a selection of studies. Almost all studies include some proxy for climate or season, and many adjust for family size or composition. Proxies for house and plot size, and water-saving equipment are less popular.

Table 2.1: Shift variables in residential water demand models

Reference	Climate or season	House or garden size	Efficient technology	Family composition
Wong, 1972	yes			
Foster and Beattie, 1979	yes			yes
Griffin and Chang, 1991	yes			
Schneider &Whitlatch, '91	yes	yes		yes
Lyman, 1992	yes	yes		yes
Agthe and Billings, 1996				yes
Renwick & Archibald,'98	yes	yes	yes	yes

Espey et al's 1997 review of residential demand models reports a median short-run price elasticity of –0.38 and a long-run median value of –0.64. According to them, some of the variation is due to methodological differences, but the time horizon also plays a role. Long-run demand is more elastic, because in the longer run consumers substitute water-saving technology for water. Installing micro irrigation in gardens or low-flow bathroom and kitchen fixtures are much less feasible in the short-run, so that the average consumer is less able to respond to a price increase in the short run.

Apart from time horizon price elasticity of demand is affected by type of use. Veck and Bill (undated) estimate price elasticity of indoor demand to be highly inelastic at –0.13, while price outdoor demand is estimated to be somewhat less inelastic at –0.38 in Alberton-Thokoza in South Africa. Moreover, more inelastic indoor demand is usually correlated with higher marginal willingness-to-pay for drinking water. There is evidence from Europe, the United States of America and Africa that households are willing to pay much more for drinking water and basic needs than for water used to irrigate gardens (Foster and Beattie, 1979; Zabel et al, 1998; Rogerson, 1996).

One of the most noticeable features of the South African landscape is the marked difference between socio-economic conditions in affluent formally settled suburbs and the informal squatter camps where a large proportion of the urban poor resides. The income differences suggest a hypothesis that separate demand curves apply to formally settled communities and informal settlements.

On the other hand both groups of consumers are fundamentally the same and the law of demand applies to rich and poor alike. An extensive study of domestic water demand in low-income communities in the northern parts of South Africa finds that demand in squatter camps obey the same rules as demand in formal settlements. As in formal settlements, quantity demanded in squatter camps is a function of income, price of water, the presence of gardens, awareness of scarcity, time of the day, season, number of household members and the number of visitors (Van Schalkwyk, 1996).

2.3. Demand management in a production setting

The basic ideas on demand management developed in the consumption setting apply directly to a situation where water is used as a factor of production, and yet, demand management is much harder to implement in a production setting. The reason is that irrigation dominates the use of water in production. Irrigation uses large quantities of water in a dispersed fashion that is closely linked to the natural cycle of water in the environment and irrigation water is almost never volumetrically priced. It is sometimes provided free of charge and in South Africa often sold as a flat rate per hectare.

Two themes are prominent when reviewing the possibilities of demand management of irrigation water, namely the institution of allocation (or the means of achieving demand management) and the practical considerations of estimating irrigation demand.

Within the allocation theme the key questions are marginal versus average cost pricing, the role of administrative pricing versus the role of markets and volumetric versus other systems of pricing. When trying to estimate the irrigation demand function the core issues are the exact nature of plant-water relationships, the range of farmer responses that should be considered and the practical constraints on modelling those responses.

2.3.1. Marginal cost versus average cost pricing

It was argued in the previous section that price is the chief instrument of demand management, and that demand management's objective is to communicate opportunity cost (or economic value) to ensure an optimal allocation of scarce resources. It is then appropriate to ask how price reveals scarcity, and which price achieves optimal allocation. The literature identifies average cost pricing and marginal cost pricing as potential candidates and this section in turn examines the ability of each to ensure optimal resource allocation.

2.3.1.1. The case for marginal cost pricing

The simple case of marginal cost pricing is powerfully argued as follows:

> "Economic theory clearly shows that if perfectly competitive conditions are satisfied and externalities are absent, the market prices will reflect social values and if long-run marginal cost pricing is followed in the pricing of irrigation water, then the corresponding levels of investment in irrigation projects and the resulting social benefits will be optimal."
>
> Sampath, 1992

Marginal cost pricing leads to economic efficiency, which is different – but seldom separated – from technical efficiency. Technical efficiency does not imply economic efficiency even though the two coincide under perfect competition. Technical efficiency is necessary, but not sufficient, for optimal allocation.

Penzhorn and Marais (1998) provide an example of arguing optimal allocation based on technical efficiency. The paper presents econometric estimates of crop-water functions, in particular total product and average product functions for maize, pearl millet and sorghum and states that whereas total product is maximised at the highest level of water input, average product (kg/mm) achieves its maximum at a lower, deficit irrigation, water level. It proceeds to define optimum water application as the irrigation level that produces the highest average product of water and concludes that production cost is minimised by applying the optimal water level. It fails to indicate that the conclusion only holds under the assumptions for perfect competition, and is a long-run result.

One of the standard definitions of technical efficiency is to produce the best possible output per unit of input, in other words at the point where average value product is at a maximum, that is w* in figure 2.1. A more general definition of technical efficiency is that it eliminates all waste. No waste could mean that for a given input level maximum output is reached, or that a given output is achieved with minimum (cost) inputs. The economic interpretation of the first option is that production occurs on the production frontier while the second interpretation corresponds to minimum short-run average costs (Church and Ware, 2000). The latter definition loosely matches maximum average value product.

Allocative efficiency on the other hand is the allocation, which given the typical assumptions about social welfare functions, maximises the sum of producer and consumer surplus, producing the greatest good for all. An industry is allocatively efficient when marginal social cost equals marginal social benefit. Abstracting from externalities, profit maximisation ensures allocative efficiency if the industry is perfectly competitive, and then only in the long run.

Figure 2.1 illustrates the difference between technical and economic efficiency. For the sake of simplicity it is assumed that output price is unitary, so that value product is equal to physical product. The top panel relates water inputs to total product of an unspecified output in a typical three-stage polynomial function. The bottom panel shows the associated average product and marginal product curves.

In stage I of production each marginal unit of water increases average product. In stage II both average and marginal product are still positive, but the marginal unit contributes less that average product causing both functions to decrease and in stage III marginal product is negative, so that total product decreases. Penzhorn and Marais's (1998) maximum production occurs on the boundary of stage II and III at water input w' and their optimal production corresponds to water level, w*. These conditions are derived from technical efficiency rather than profit maximisation, so that choosing to apply w* is not optimal in an economic sense.

Profit maximising production occurs somewhere in stage II of production. Producers will never choose to produce in stage I, because they can improve average output by increasing inputs, and they will likewise never produce in stage III, because they can increase output by reducing inputs. The section of the marginal value product function between w* and w' is the farm's water demand curve. The exact point where profits are maximised depends on the market price. Under perfect competition, where firms are free to enter and leave the market price for water is equal to the maximum of average value product for the marginal firm in the long run.

The general condition for technical efficiency used by Penzhorn and Marais (1998) to denote optimal allocation only applies to the marginal firm when allocative efficiency is achieved. Unless the assumption is made that all firms have identical cost structures, non-marginal firms apply an optimal water level between w* and w'. Such an allocation is optimal in the sense that it achieves the greatest social good, given the additional assumptions summarised by Sampath (1992) and outlined above.

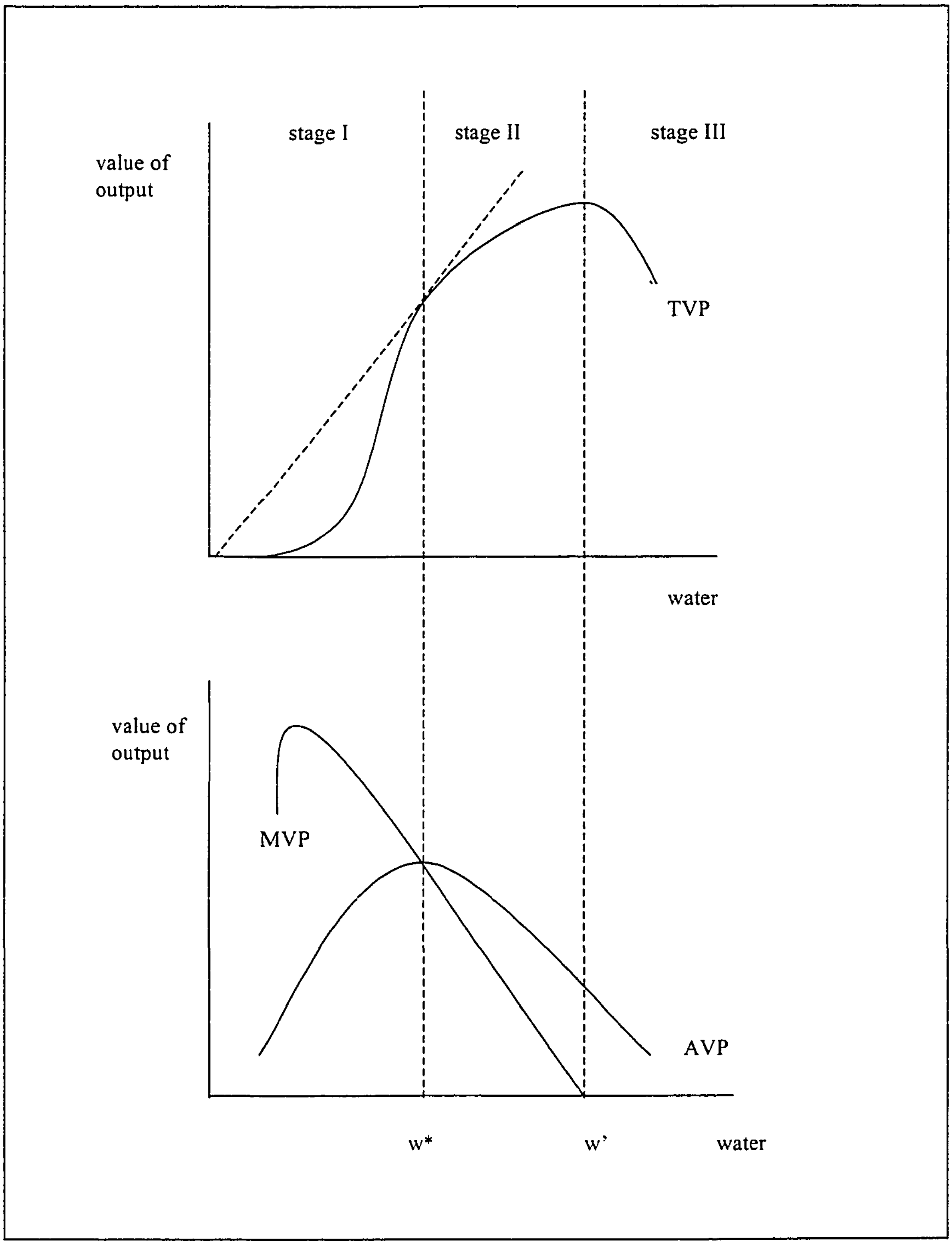


Figure 2.1: Total product, average product and marginal product

2.3.1.2. The case for average cost pricing

Average cost pricing is recommended as a strategy to finance (public) natural monopolies such as water companies. Varian (1993) gives a very simple explanation of the problem, which revolves around regulating a public monopoly to be Pareto efficient by forcing it to set price equal to marginal cost. This form of regulation removes the water company's monopoly power and results in quantity supplied at the level where price equals marginal cost, thus maximising the sum of producer and consumer surplus.

However, on the downward sloping section of average total cost, marginal cost is below average total cost rendering the regulation strategy unrealistic. For this range of output marginal cost pricing is efficient, but not profitable (Varian, 1993). Area a in figure 2.2 indicates the magnitude of the loss incurred. Average cost pricing is superior to the unregulated monopoly outcome because it produces a larger consumer surplus, and is preferred to marginal cost-pricing since it allows full cost recovery.

Cost recovery is a prerequisite for attracting private investment in municipal water supply services and privatising water services is a potential way of ensuring a better level of service. However, there is very little evidence that full cost recovery is possible in irrigation settings (Burness et al, 1983; Sampath, 1992; Cummings and Nercissiantz, 1992; Tsur and Dinar, 1995). Average cost pricing of municipal water is widely used in the First World and even recently in parts of the Third World. It is recommended for South Africa, and is permitted by the National Water Act (Act 36 of 1998) (Silva et al, 1998; Zabel et al, 1998; Schur, 1994; Eberhard, undated; Randall, 1981).

Tsur and Dinar (1995) recommend that average cost and marginal cost pricing are combined in a single pricing system where fixed costs are recovered according to average cost principles, while marginal cost pricing is used for the variable component of operation costs. This system ensures full cost recover, and financial security for the water company, while at the same time providing an accurate signal of scarcity.

2.3.2. Theoretical approaches to pricing irrigation water

The previous section calls for marginal cost pricing to ensure optimal allocation of water used in production. This section reviews three alternative systems for pricing irrigation water, namely volumetric rates, flat rates and output-based rates as suggested by Tsur and Dinar (1995). Flat rates are preferred in South Africa – as in Nigeria, Peru and Iraq to name a few – due to ease of administration.

Volumetric rates treat water as a variable input with a constant unit price, flat rates imply that water is a fixed factor of production and output-based rates assume a fixed relationship between output and the water input.

2.3.2.1. Volumetric rates

Profit maximisation, and the resulting optimal input level, only takes account of variable factors of production. Hence, any attempt at pricing water to ensure optimal use presupposes that water is a variable input in production. This in turn requires volumetric rates.

The individual farmer's profit maximisation problem is given by expression [1] and let the social problem be to maximise net benefit of irrigation for n farmers who can each potentially farm L_i hectare land.

Let:

y	output
f(x, w)	production function
x	other variable inputs per hectare, potentially a vector of other inputs
w	water applied per hectare
v	water price
r	other input price, potentially a vector corresponding to the number of inputs
p	output price
Π	profits per hectare
C(y)	cost function
MC(y)	marginal cost, the total derivative of the cost function with respect to output
L_i	irrigated area of farmer i

In input space per hectare profit maximisation is defined as:

$$\Pi = pf(x,w) - rx - vw \qquad [1]$$

The first order necessary conditions for profit maximisation are

$$\frac{\partial \Pi}{\partial x} \rightarrow pf_x(x,w) - r = 0$$

[2]

and

$$\frac{\partial \Pi}{\partial w} \rightarrow pf_w(x,w) - v = 0$$

[3]

The social problem for the irrigation scheme aggregates per hectare private profits across individual holdings and all farmers, and subtracts the scheme's costs, net of total water rates collected.

$$B(p,r,v)=\sum_{i=1}^{n}\left(L_i\left[pf_i\left(x_i(p,r,v),w_i(p,r,v)\right)-rx_i(p,r,v)-vw_i(p,r,v)\right]\right)-C\left(W(p,r,v)\right)+\sum_{i=1}^{n}L_i v w_i(p,r,v)$$

[4]

where:

W total water applied by all farmers
C(W) long-run total cost of operating the irrigation scheme

The parameters of the social problem are output price, other input price(s) and water price. The parameters determine per hectare private profits, which in turn establishes the optimal level of water application per hectare. The present specification implies a single production function, and farmers can only decide to produce, or not produce, but production functions are farm specific, allowing for resource heterogeneity. Tsur and Dinar (1995) explain that it is possible to allow for different crops on each farm, but the only relevant production function is that of the most profitable crop.

Water payments are a cost to farmers and an income to the government, but the transfer does not add to total benefit. What the farmers pay is equal to the government's income, so that [4] simplifies to:

$$B(p,r,v)=\sum_{i=1}^{n}\left(L_i\left[pf_i\left(x_i(p,r,v),w_i(p,r,v)\right)-rx_i(p,r,v)\right]\right)-C\left(W(p,r,v)\right)$$

[5]

To maximise social benefit, the following first order condition must hold for the social benefit function:

$$\frac{\partial B}{\partial v}\rightarrow\sum_{i=1}^{n}L_i\left(pf_{ix}\frac{\partial x_i}{\partial r}+pf_{iw}\frac{\partial w_i}{\partial v}\frac{\partial x_i}{\partial r}-r\frac{\partial x_i}{\partial r}-\frac{\partial C}{\partial w_i}\frac{\partial w_i}{\partial v}\right)=0$$

[6]

Grouping like terms [7] becomes:

$$\sum_{i=1}^{n} L_i \left((pf_{ix} - r)\frac{\partial x_i}{\partial r} + pf_{iw}\frac{\partial w_i}{\partial v} - \frac{\partial C}{\partial w_i}\frac{\partial w_i}{\partial v} \right) = 0$$

[7]

Since the first order condition of the private problem ensures that marginal value product of water is equal to factor cost for each farmer (expression [2]), the first order condition of the social benefit function in [7] simplifies to:

$$\sum_{i=1}^{n} L_i \left(pf_{iw} - \frac{\partial C}{\partial w_i} \right) \frac{\partial w_i}{\partial v} = 0$$

[8]

Tsur and Dinar (1995) suggest that [8] can only be true if [2] holds such that

$$v = \frac{\partial C}{\partial W}$$

[9]

The price, v, is a marginal cost price, and expression [9] confirms that marginal cost pricing is efficient, because it maximises social welfare.

2.3.2.2. Flat rates

The case for volumetric pricing is clear, but the cost of implementing measurement may outweigh the benefits of volumetric rates compared to flat rates. Furthermore, it may not be possible to deliver varying quantities in response to demand due to limited distribution capacity (Sampath, 1992). Some argue that it is therefore practical to price water as a flat rate per hectare and supply the entire allocation at a prearranged maximum rate.

While flat rates may seem to fit better with the realities of selling irrigation water, this system turns water into a fixed cost. The private problem changes to:

$$\Pi = pf(w,x) - rx - FL$$

[10]

where

FL flat rate per hectare

The necessary first order conditions of the private problem become:

$$\frac{\partial \Pi}{\partial w} \rightarrow pf_w(x, w) = 0 \qquad [11]$$

and

$$\frac{\partial \Pi}{\partial x} \rightarrow pf_x(x, w) - r = 0 \qquad [12]$$

The social problem is of the same form as [4]:

$$B(p, r, FL) = \sum_{i=1}^{n} L_i (pf_i(x(p, r), w(p, r)) - rx(p, r) - FL) - C(W) + \sum_{i=1}^{n} L_i FL \qquad [13]$$

Again the transfer from producers to the government does not affect net social benefit, reducing [13] to:

$$B(p, r, FL) = \sum_{i=1}^{n} L_i (pf_i(x_i(p, r), w_i(p, r)) - rx_i(p, r)) - C(W) \qquad [14]$$

It is clear from expression [10] that flat rates are a cost item, which reduce the individual farmer's profits, and from expressions [11] and [14] that the magnitude of the flat rate does not affect the quantity of water used.

The necessary condition for profit maximisation sets the marginal value product of water equal to zero in [10]. The magnitude of the flat rate only decides who produces and who does not produce, since expression [10] holds for the marginal producer only. If the flat rate is sufficiently high, the marginal producer goes out of business.

Viewing water allocation as the marginal farmer being in or out of production is a long run formulation of the problem, and is consistent with the objective of demand management. The objective is not so much to control how farmers irrigate from day to day, but to ensure that high value uses have access to a scarce resource rather than use categories that attach low value to the marginal unit of water. In the long run a flat rate water cost is variable, as is the cost of the irrigation system, and farmers can thus substitute away from highly priced water to cheaper irrigation equipment.

Moreover, a static long-run formulation is consistent with the evidence that the level of water demand is affected by flat rates. Griffin and Perry (1985) estimate farm level demand as a function of volumetric price and flat rates. They hypothesise that the OLS coefficient on the flat rate will be unimportant and insignificant, while the volumetric water price will be negative and highly significant. Both coefficients are found to be negative and very significant.

Griffin and Perry (1985) offer several reasons why farmers would respond to flat rates despite the theoretical prediction, arguing that when flat rates are high, non-price effects kick in. For example, water agencies monitor farmers carefully for inefficient water use, canals are more carefully managed and producer awareness is generally higher. All these explanations are plausible, but unsubstantiated and lower demand may simply be due to marginal land being taken out of production, or marginal farmers going out of business.

2.3.2.3. Rates based on products or factors of production

Output- or input-based water rates are more of a theoretical curiosity than directly applicable to South African conditions. An output-based rate defines the water fee as a per unit tax on product sales, while an input-based rate levies the water fee as a unit tax on input prices. The approach makes a valuable general point, though. If it is difficult to count a particular type of use, but easy to find data on another input that is used in a fixed proportion to water, water use can be inferred from, and controlled through the price of the other input.

In the case of input based rates a charge for water will be added to the price, of say, fertiliser on the assumption that a higher fertiliser price will reduce fertiliser use, as well as associated water use. This approach is crude, but at least it lines up the incentives for water saving properly. Likewise, with output based charges producers pay a fixed fee per unit of crop produced. The water charge reduces output price, which lowers the profit maximising level of output, which in turn reduces water use.

For output-based rates the private problem is:

$$\Pi = (p - z)f(x, w) - rx \qquad [15]$$

The first order conditions for per hectare profit maximisation is:

$$\frac{\partial \Pi}{\partial x} \rightarrow (p-z)f_x - r = 0$$

[16]

and

$$\frac{\partial \Pi}{\partial w} \rightarrow (p-z)f_x = 0$$

[17]

Again, the amount paid as water rates is counted as government income, so that the net social benefit is unaffected. The simplified social problem corresponding to [5] and [14] for n farmers paying output-based water rates is:

$$B(p,r,z) = \sum_{i=1}^{n} L_i\left(pf\left(x(p,r,z), w(p,r,z)\right) - rx(p,r,z)\right) - C(W)$$

[18]

Assuming identical per hectare production functions for all farmers, one can solve for the optimal output-based water price. The rate that maximises net benefit, if it exists, rests on the following condition:

$$\frac{\partial B}{\partial z} \rightarrow pf_x \frac{\partial x}{\partial z} + pf_w \frac{\partial w}{\partial z} - r\frac{\partial x}{\partial z} - \frac{\partial C}{\partial w}\frac{\partial w}{\partial z} = 0$$

[19]

From [16] and by rearranging:

$$(pf_x - r)\frac{\partial x}{\partial z} + pf_w \frac{\partial w}{\partial z} - \frac{\partial C}{\partial w}\frac{\partial w}{\partial z} = 0$$

$$zf_x \frac{\partial x}{\partial z} - \frac{\partial C}{\partial w}\frac{\partial w}{\partial z} = 0$$

$$z\frac{r}{p-z}\frac{\partial x}{\partial z} - \frac{\partial C}{\partial w}\frac{\partial w}{\partial z} = 0$$

$$z = \frac{p}{\dfrac{r\dfrac{\partial x}{\partial z}}{\dfrac{\partial C}{\partial w}\dfrac{\partial x}{\partial z}} + 1}$$

[20]

Expression [20] is the optimal fee as long as the production function is strictly concave, the cross products of the production function is positive and $p > z$ (Tsur and Dinar, 1995).

2.3.3. Administrative prices versus markets

The previous section discussed practical pricing strategies, assuming that administrative pricing is the best institution for allocation. This section compares administrative pricing to water markets.

Some, mostly government agencies, feel that the government needs to intervene directly by setting water prices administratively, while others, especially economists, argue that the appropriate role of government is to ensure that markets function properly:

> " Perhaps, instead of emphasizing the problem of getting prices right, we should emphasize getting rights right, in which case prices will take care of themselves"
>
> Schmid 1990 in Backeberg, 1995

Directly opposed to the free market position is the opinion that governments need direct control over the allocation of irrigation water. The direct control position is generally defended on two assertions, namely the economies of scale argument and the role of irrigation in rural development.

2.3.3.1. The case for administrative prices

By definition administrative pricing is a leasing arrangement, and the "price" is an annual "user fee". This arrangement does not specify the duration of the contract, which could be a permanent right (to lease water from the society) or a 40-year license, as is proposed for South Africa.

Colby (1990) points out that a water market may consist of transactions to transfer water "either for a limited time or into perpetuity" while Bruggink (1992) refers to a "perpetual right to an annual flow". Backeberg (1995) makes a distinction between a market for water rights and a market for the use of water, called a spot market in the American literature.

Nieuwoudt (2000) shows that there is no conflict between public ownership of water rights and a market for trading the usufructary benefits of the resource. Nieuwoudt's position in other words refutes the idea that society's joint ownership of the resource implies administrative pricing.

The most convincing argument for administrative prices as instruments of demand management is that the nature of the water resource makes private property rights impractical. Markets cannot function properly because water rights cannot be specified in full. The lack of unattenated property rights lead to negative quality and return-flow externalities that need to be accounted for before markets will allocate efficiently.

Few people questions that government should act as a custodian of a resource that belongs to society as a whole, but the question remains if it is possible to effectively protect the resource by carefully designing the institutions. Proponents of administrative pricing argue that it is not possible to ensure sustainable resource use unless the government has direct control over resource allocation.

The same arguments that apply to basic needs water on the consumption side, are also used to argue for direct government involvement in allocating irrigation water. For example, Sampath (1992) calls for direct government involvement in water allocation on the grounds that litigation, which is the final referee regarding allocation, is an expensive process that discriminates against the poor. He also points out, quoting South East Asian and Indian evidence, that direct control over irrigation provides governments with an instrument for income redistribution. Again, the argument is that general taxes should fund rural development rather than the poor themselves.

2.3.3.2. The case for water markets

The greatest advantages of market allocation as exactly those aspects of the allocation process at which administrative pricing fail, and vice versa. The two most important arguments for water markets are that it attaches opportunity cost to water and that it is self-adjusting (Randall, 1981; Sampath, 1992; Backeberg, 1994; Armitage et al, 1999). The opportunity cost argument is that if water can be sold, the farmer has to derive as least as much benefit from using the water as he could make leasing the water. Theoretically water taken up by low value users will be released onto a market where it can be redistributed to more beneficial applications. Moreover, in a market that functions properly, the reallocation process is automatic.

The necessary conditions for properly functioning water markets have been documented in detail (Randall, 1981; Colby, 1990; Cummings and Nercissiantz, 1992; Dudley, 1992; Griffin and Hsu, 1993; Michelsen and Young, 1993; Backeberg 1995; Streeter, 1997; Turner and Perry, 1997; Armitage et al, 1999; Michelsen et al, 2000; Nieuwoudt, 2000). Bruggink (1992) also extends the conditions to more problematic groundwater markets.

The requirements summarise as follows:

1. Fully defined water rights, specifically,
   - time and place of delivery as well as the time horizon of the contract
   - third party impacts, that is ownership of tailwaters, returnflows and the right to pollute/clean water and responsibilities must be specified
   - specification of how the stochastic nature of supply affect the entitlement, in other words, how droughts will be handled
   - the conditions for leasing water should be defined

2. Property rights must be enforceable, implying that the owner of water right must be able to claim the benefits flowing from those rights.

3. Exclusive rights to the water must be guaranteed and water right must exist separately from property rights to the land.

4. Realistic knowledge on both sides, including the knowledge of opportunities to buy and sell.

5. Low transaction costs, that is clear rules of transfer and an enabling administrative procedure.

6. Flexible conveyance systems, in other words one must be able to physically reallocate the water.

The specific conditions summarise to full information and low transaction costs. When this is the case, the market price will automatically adjust to reflect all stakeholders' subjective values for water. In this regard markets are far superior to administrative pricing systems, where it is impossible or very impractical to charge a current price due to the stochastic nature of water supplies (Sampath, 1992; Nieuwoudt, 2000).

Fully specifying property rights are costly, but various suggestions have been made. For example Marshall et al (1996) propose integrated catchment management as a system where bargaining is used to specify property rights more fully. It implies that the appropriate role for government is to lower transaction costs of water transfers.

One of the important arguments against water markets is that imperfectly specified water rights lead to down-stream externalities. This happens because water rights are usually specified in terms of diversions, with no specific rights to the quality of diversion, and no limit on the quantity or quality of water returned to the river. Furthermore, it is typically not possible to hold rights to streamflow that is not diverted, at least not under the prior appropriate doctrine such as applies in the American West. Various authors have argued that markets lead to fewer externalities because a market price attaches an opportunity cost to water which limits diversion. Less diversion leads to fewer environmental externalities (Randall, 1981; Colby-Saliba, 1985; Colby, 1990; Jones and Fagan, 1996).

Moreover, water markets provide the ideal mechanism to internalise some environmental externalities, provided that instream flows are recognised as beneficiary use. Instead of having to subjectively value environmental services in an attempt to quantify environmental reserves, a market allows environmental interest groups to secure rights guaranteeing the flows they deem optimal Colby (1990).

The final point to make in the case for water markets is what is traded. As stated above, it can be either a permanent right to future flows or an actual volume available at a given point in time. Trading of rights to future flows seems simpler at first, because such private property rights are defined although imperfectly. The same is not true for spot markets, though anecdotal evidence of short term leases have been documented in South Africa and the American West (Nieuwoudt, 2000). However, as rights markets mature, flows have to be volumetrically measured, which if the distribution network permits, creates the technical information on which a leasing market would rely.

Dudley (1992) proposes a capacity sharing arrangement whereby each right holder, or group of rights holders, shares in the capacity of a water system. Right holders share in reservoir inflows, as well as systems losses, and each decision-maker controls his share without interference from any other shareholder. The system requires a continuous accounting of stocks and flows of each shareholder, but improves efficiency by improving certainty of supply to individual water users.

2.3.3.3. Evidence of water markets

The Colorado River has been the subject of intensive study over many years, and table 2.2 reports a range of simulated irrigation values for the river. For example, Michelsen and Young (1993) calculate a water value of $85/ac-ft, and Booker and Young (1994) value irrigation water at $20/ac-ft. Taylor and Young (1995) calculate a value similar to that of Michelsen and Young (1993) for water short years and estimate water value to be about the same as Booker and Young's (1994) estimate in normal years. Howe's 1985 maximum estimate of water values for crop production in the Colorado River is $21.15/ac-ft and Turner and Perry (1997) come to a similar conclusion for the Deschutes River in Oregon.

Most of the market values in table 2.2 are simulated, but the Northern Colorado Water Conservancy District (NCWCD) provides an example of a functioning water market (Cummings and Nercissiantz, 1992; Nieuwoudt, 2000). The company distributes available water based on shares somewhat like those proposed by Dudley (1992). Declaring the annual volume of water available per share incorporates seasonal variability of supply. The difference between NCWCD shares and capacity sharing is that in the latter case shareholders decide on the pattern of releases while the NCWCD Water Company chooses the pattern of releases. NCWCD shares are actively traded among agricultural users and between agriculture and non-agricultural users. Apart from a market for shares water is often leased in spot markets. The present value of share price is $3 000/ac-ft and the right leases for $15/ac-ft (Nieuwoudt, 2000).

Table 2.2: Market values for water

Location	Description of market	Comments	Reference
Colorado River	Observed average value products of irrigated agriculture	Average value product range between -$13.88 for barley and $40/ac-ft for lucerne. Basin average is $21.15/ac-ft. for all crops.	Howe, 1985
Northern Colorado	Members of the NCWCD	Water rights values fell from $2 895 (1980) to $900 (1985)	Cummings and Nercissiantz, 1992
Cache la Poudre River, Colorado	Irrigation offering price	Simulated value of $85/ac-ft ($39-135) system consisting of Lucerne and field crops	Michelsen and Young, 1993
Colorado River	Irrigation, hydropower, municipal use	Simulated intrastate markets calculate irrigation values of $20/ac-ft and $300/ac-ft for municipal use	Booker and Young, 1994
Utah	Irrigation, hydropower, municipalities and investors	Prices of water rights reflect a quality difference of $665/ac-ft	Colby Saliba, 1995
Southeastern Colorado	Irrigation selling to municipal use	Value of irrigation water is $9-27/ac-ft at present use levels, and increase to $90 in water short years	Taylor and Young, 1995
Deschutes River, Oregon	Agricultural willingness-to-sell	Simulated results show that a third of the water needed for instream flows could be leased at $25/ac-ft	Turner and Perry, 1997
Orange River, South Africa	Irrigation selling to irrigation	Water rights sell for R3 000-R3 500/ha. The quota is 15000 m^3/ha	Armitage et al, 1999
Northern Colorado	Irrigation to irrigation	Water leases for $15/acft and sells for $3 000/ac-ft	Nieuwoudt, 2000

Armitage et al (1999) report anecdotal evidence of a spontaneous water market in South Africa. Farmers informally trade water rights associated with undeveloped land. The sellers would use water to irrigate fodder and other field crops, and the buyers intend to develop irrigated table grape developments downstream of traditional irrigation areas. The marginal value product of water on unused land is zero, and theory suggests that such farmers will be selling at any positive water price. Armitage et al (1999) find that permanent water rights trade for roughly double the price of arable land with no water rights. It is concluded that this market emerged because of the presence of willing sellers, low transaction costs and a high level of assurance.

Dry year optioning provides a cost saving alternative to outright purchasing of water rights (Michelsen and Young, 1993). It is argued that the basic preconditions for an option market are the same as for the market of water rights. The cost saving associated with choosing optioning over an outright purchase of water depends on a variety of financial assumptions, but the key variable seems to be the probability of a drought occurring. When the chance of a drought is one in twenty, options have significant net benefit, but when a drought is expected to occur once every four years, it is less expensive to buy rights outright than to buy a dry year option. Dry year options are only feasible where agricultural operations can be suspended for a year without affection subsequent profitability, as in the case of annual crops. This institution is not suitable for orchards (Michelsen and Young, 1993).

2.3.3.4. Markets and equity

An unfortunate reality of market allocation is that only those with sufficient incomes are permitted to compete for scarce resources. In a study in Perth, Western Australia, it was found that 80 percent of respondents considered market allocation to be unfair and a third of the sample wanted equal water for all households (Syme and Fenton, 1993). Since unequal income distribution is such a striking feature of South African society, the market is no solution if not accompanied by a suggestion to accommodate the poor. Unless equity is considered alongside efficiency a lack of equity causes a "social malaise that leads to high inefficiency costs" (Howe, 1996). Backeberg's (1995) solution combines water markets with lump-sum transfers to change income distribution, including education, transferring government property to the poor and cash payments. The National Water Act (Act 36 of 1998) provides partial access by allocating 25 litres per person per day free of charge or at a very low cost. The proposed increasing block rates for municipal water will further provide access for the poor.

2.3.4. Modelling irrigation

This section examines the difficulties of modelling irrigation including evidence of plant-water relationships, water versus irrigation, hypothesised farmer responses and consumptive versus diverted use.

2.3.4.1. Plant-water relationships

At least four types of plant-water relationships are described in the agronomy and water literature. The most widely known of these is the polynomial function of the type $y = ax + bx^2 - cx^3$, used in the top panel of figure 2.1. The other candidates, presented in figure 2.2, are quadratic relationships of the form $y = ax - bx^2$, and Spillman and Von Liebig functions. Spillman, $y = a - b(1 - R^x)$ where 0 < R <1, is a continuous version of the Von Liebig, or linear plateau function, where $y = \min[y_{max}, bx]$.

The original plant-water relationships were modelled as polynomial functions (Flinn and Musgrave, 1967; Anderson and Maas, 1974). More recent examples use functions that approximate the relevant portion of the polynomial function, which is stage II of production. When it comes to choosing the most appropriate function, the key question is if too much water can harm output. Output eventually decreases for polynomial functions and quadratic functions such as used by Hoyt (1983) and Hoyt (1984). A notable early exception is Hanson (1965) whose "polynomial" production function depicts stage III as a plateau. This view is supported by proponents of the linear plateau function and Spillman functions (Minhas et al, 1974; Stegman et al, 1980; Musick et al, 1974).

Hanks and Rasmussen (1982) review the development of plant-water models, starting with the relationship between transpiration and yield that was first proposed by Briggs and Shantz in 1927, and ending with the Morgan, Biere and Kanemasu model, which also uses a linear plateau function. Various authors model salinity damage as linear plateau functions (Maas and Hoffman, 1976; Feinerman and Yaron, 1983; Lefkoff and Gorelick, 1990). Hanks (1984) uses the continuous approximation of the linear plateau function and Warrick (1989) models both water deficits and salinity simultaneously with a combination of linear plateau functions.

While a very intuitive relationship, the economist's problem with linear plateau models is apparent. The first derivative of this production function is discontinuous and consists of two horizontal sections. The linear upward section has a positive derivative and the plateau's first derivative is zero. Profit maximisation leads to production at the kink or no production at all. If the price of water is greater than the positive section of marginal value product in the lower panel of figure 2.3, zero is optimal. If the price of water is lower than this, w* is the optimal water input. Higher water inputs do not achieve a higher output, and are therefore not rational. Note that w* in figure 2.3 is both the maximum of total product and the maximum of marginal and average product, so that Penzhorn and Marais's (1998) rule for optimality breaks down.

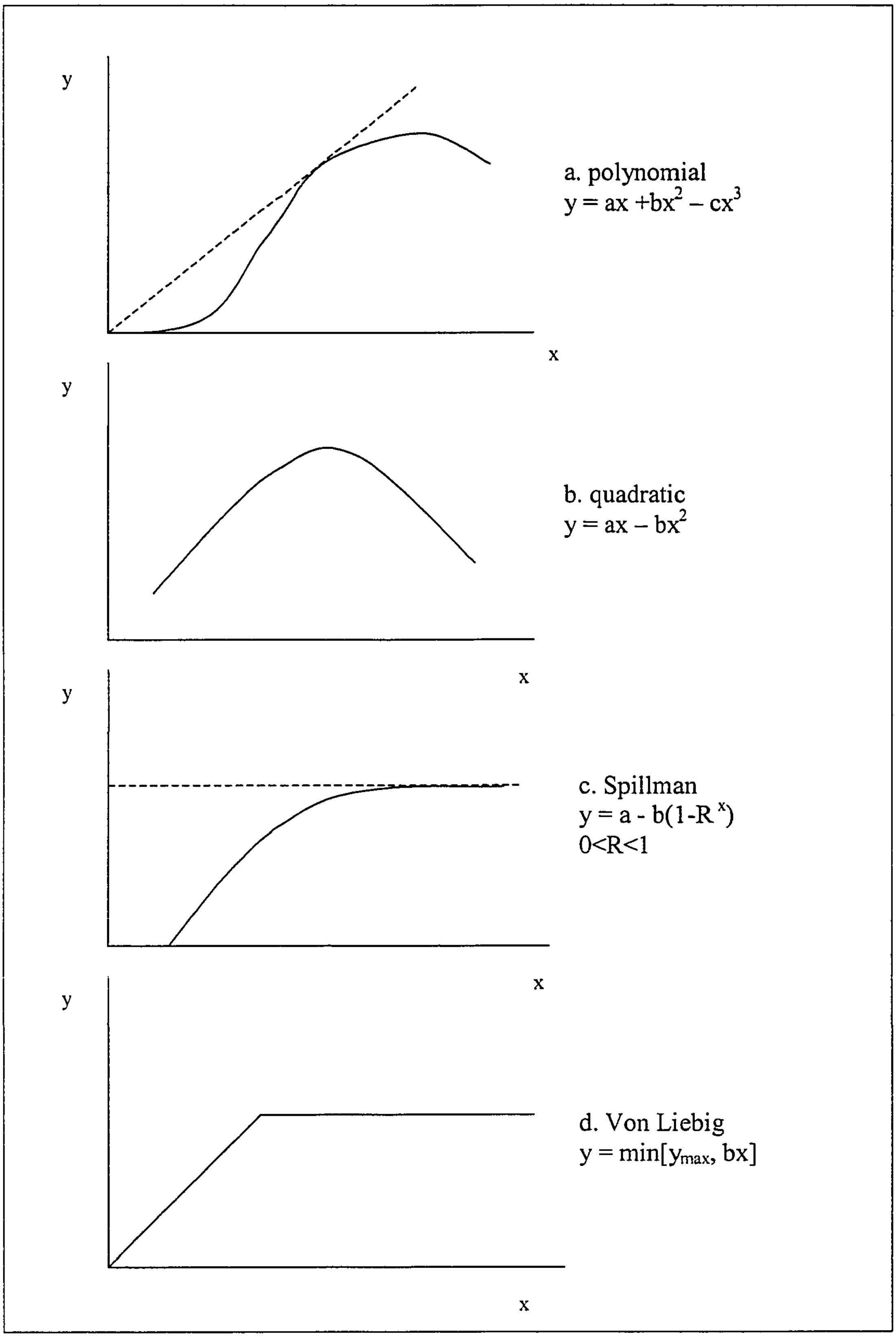


Figure 2.2: Functional forms for plant-water relationships where x is water

This evidence suggests that there is not opportunity for deficit irrigation. According to the linear plateau function there is one optimal level of irrigation regardless of water price, and if the water price is too high production shuts down. Under these assumptions all that demand management can hope to achieve is to put entire categories of irrigators out of production, starting with the least profitable. The shutdown point will among others be affected by irrigation system suggesting that flood irrigators may go out of business before users of drip irrigation. The hypotheses remain to be confirmed, but it is clear that despite the strong implications of the linear plateau model, it may still allow the type of policy outcome that demand management aims for.

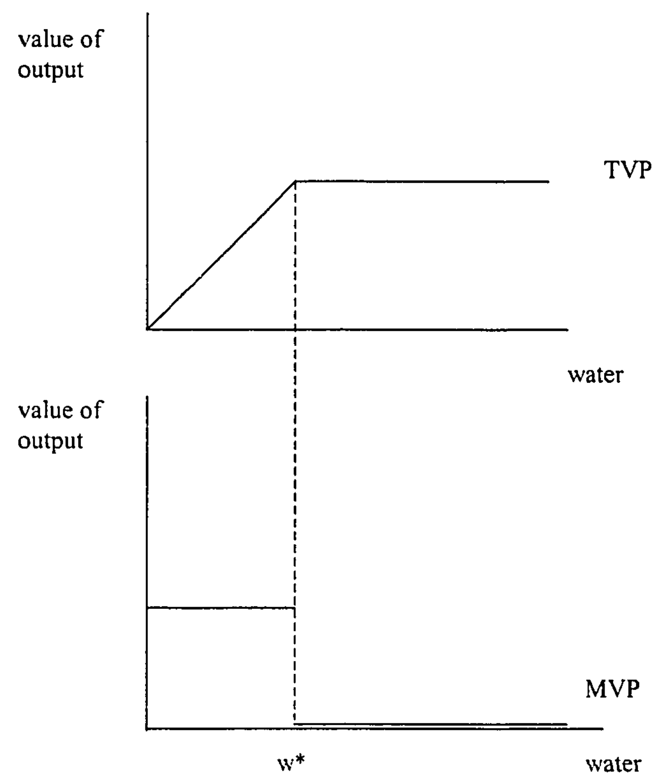


Figure 2.3: Profit maximisation for a linear plateau production function

Warrick and Gardner (1983) show that as the variability of soil and irrigation increases, the linear plateau plant-water relationship approximates a Spillman function. The advantage is that the first derivative of the Spillman function is continuous, but its implications are identical to that of the linear plateau model. As long as the kink is fairly well defined, irrigation is an all-or-nothing decision. Only if the kink is quite stretched out, in other words at high levels of variability, does it produce a downward sloping marginal value product curve of the kind that allows demand management.

2.3.4.2. Water versus irrigation

The discussion so far makes no distinction between water and irrigation. Water, not irrigation, affects plants. Plant-water relationships are a matter of measurable plant physiology, and capture the relationship between dry matter formation and evapotranspiration (Hanks and Rasmussen, 1982). Irrigation, on the other hand, is a bundle of water, capital and management inputs that delivers water from a distant source to plants in a field. The production function in figure 2.1 relates output to water for a given (fixed) irrigation system (and fixed levels of other). A change in technology, even as slight as a change in timing of irrigation, is defined as a new production function.

One of the first papers to make this point explicitly shows the production function shifting back in response to water stress in various critical growth periods (Flinn and Musgrave, 1967). This idea is still used by McGuckin et al (1987) who assume that a season's yields consist of the sum of growth stage increments. Some argue that it is not the total amount of water that matters, but the timing, which calls for dynamic optimisation to determine optimal scheduling in the presence of uncertain water supplies. See for example Hall and Butcher (1968) and Soltani et al (1992) on the production function and Bryant et al (1993) for farm-level applications. Lee and Howitt (1996) derive an explicit shift function.

Dynamic optimisation is the appropriate model to answer questions about the best farm-level allocation strategy. Assuming that it is impractical to administratively set a range of intra-seasonal prices, it is clear that the appropriate analysis should take a static long-run perspective. This does not mean that Flinn and Musgrave's (1967) original idea is not useful to model different strategies. Afzal et al (1992) present a modern version of using a linear programming model to find the optimal irrigation strategy. To simplify matters irrigation is usually modelled as discreet bundles (MCGuckin et al, 1987; Gardner and Young, 1988; Mallawaarachchi et al, 1992; Bernardo et al, 1993; Booker and Young, 1994; Teague et al, 1995).

2.3.4.3. Hypothesised farmer responses

It is important to have a clear understanding of how farmers are likely to respond to higher prices when trying to model water markets. This section reviews possible responses discussed in the literature. Much confusion exists about what may happen, but it is useful to keep the following farmer perceptions about irrigation in mind (Crosby, 1994, Stilwell, 1994):

1. Irrigation is not a high priority farming activity. There is anecdotal evidence that farmers do focus on irrigation when water is scarce and supplies are unreliable, but even then only once all other farming practices are of a high standard. The implication is that extension must reflect the farmer's set of priorities rather than try to build irrigation skills in isolation.

2. Farmers are generally anxious that they are under-watering and do not appreciate the harmful effects of over-watering.

3. Farmers perceive irrigation to increase, rather than decrease, the risk of farming.

4. Technology will only be widely adopted if it is relevant to a farmer's needs and appropriate given his resources and operational circumstances.

Farmers can respond by substituting capital or management for water, or redefining their water requirement by using deficit irrigation, growing a smaller area or adjusting crop choice. It is also possible to supplement present sources with alternative supplies. Some aspects, like the irrigation system, are fixed in the short run so that adjustments have to take place over a longer period. Others, like scheduling, allow changes in response to temporary water shortages. There is evidence that farmers who do adjust are more able to cope with future droughts (Viljoen et al, 1992).

There is further proof of a gradual change from water intensive systems such as flood irrigation to water saving technology like drip irrigation (Uys et al, 1998). The hypotheses that will be discussed below all follow from the producer's profit maximisation problem, considering scenarios where some, and then all, factors of production are variable.

2.3.4.3.1. Substituting capital for water

Changing from flood to drip irrigation is an example of substituting capital for water. It is a long-run process, especially for perennial crops, that is expected to lead to significant water savings (Gaffney, 1992; Mallawaachchi et al, 1992; Turner and Perry, 1997; Du Plessis, 1998). This trend is not only sensitive to water price changes, but rather responds to changes in relative input prices. The phenomenon is possibly due to rising labour prices or for fruit quality reasons, but the reasons have not been examined explicitly for South Africa.

Laser levelling is another example of substituting capital for water. Lasering allows a more even distribution of water on a field, thereby improving the efficiency of all irrigation systems. In one of the few articles that mention laser levelling, Turner and Perry (1997) assume that laser levelling improves systems efficiency of siphon tube furrow irrigation from 50 to 55 percent, and that the efficiency of sideroll sprinklers to improve from 70 to 72.5 percent. Cornforth and Lacewell (1982) assume that laser levelling improves systems efficiency by 25 percent on flood irrigation systems.

The improvement expected from laser levelling obviously depends on the condition of the field before laser levelling. As a Cradock farmer explained, (profit maximising) "farmers tend to laser their least efficient fields first". Local estimates for the Cradock area indicates that laser levelling may improve the average systems efficiency in the area from 50 to 65 percent. As more fields are levelled the percentage improvement will approach the Turner and Perry (1997) assumption.

Possibilities to substitute capital for water are not endless (Frederiksen, 1996). Where water is already the limiting resource, raising the price of water does not cause a change in behaviour, because it does not change the relative resource price that affects optimal water application. Instead higher water prices increase the cost of irrigation and put marginal farmers out of business if dryland production is not feasible.

2.3.4.3.2. Substituting management for water

Economists often ignore management as an input in production process, but management and water are important substitutes in irrigation in the short run. Careful management requires smaller quantities to be diverted which limits returnflow. Poor knowledge of, and the inherent uncertainty about, soil-water relationships induce farmers to over-irrigate (Oosthuizen, et al, 1996a).

Management-water substitution takes the form of irrigation scheduling (Turner and Perry, 1997). Scheduling is defined as placing the optimal amount of water in the root zone to minimise deep percolation and run-off. It is possible through scheduling to decrease diversions without reducing the water available to plants. Compare this with deficit irrigation where less than the optimal amount of water is applied. Scheduling does not lead to a reduction in yield, while reduced yields are inevitable for deficit irrigation. However, the stochastic nature of rainfall impedes that can be achieved through scheduling. For example, McGuckin et al (1987) and Johnson et al (1991) found that optimal irrigation scheduling leads to less than 10 percent improvement in profits.

As in the case of capital-water substitution, it is important to note that there are other horticultural reasons for scheduling apart from the price of water. Especially fruit crops have high quality requirements, which are often tied to irrigation practices. In such cases, farmers do not schedule to save water or reduce production costs, but to ensure a high standard of fruit quality.

2.3.4.3.3. Deficit irrigation

As explained above, deficit irrigation is the choice to sacrifice yield by applying less water than required for maximum total product. Many authors agree that deficit irrigation is one of the few real ways to save water (Huffaker and Whittlesey 1995; Turner and Perry, 1997; Du Plessis, 1998).

Deficit irrigation is recommended because a less than proportional yield reduction is often observed when non-critical irrigation events are eliminated (Afzal et al, 1992). Crosby (1996) claims that it is possible to reduce water application by up to 25 percent for a yield loss of only10 percent, assuming that water is the limiting constraint and Grove and Oosthuizen (1997) report water saving more than proportional to the yield loss for Winterton, South Africa.

Bennie et al (1998) present crop- water functions for wheat, maize, peanuts, peas and potatoes calibrated to South African conditions where the effect of water stress is growth stage specific. Plants are assumed to be more sensitive to water stress during establishment and vegetative growth than in the reproductive and ripening stages.

The problem with modelling deficit irrigation is that agronomists and economists do not agree on a definition for deficit irrigation. The analysis is complicated for two reasons. The first reason relates to the difference between the production functions in figure 2.1 and 2.3 and the second reason arises from the difference between per hectare analysis and whole farm analysis. The production function in figure 2.3 has a single optimal level of irrigation, sometimes referred to as "full irrigation" (Afzal et al, 1992). Compare that to the full irrigation level in figure 2.1 where maximum yield is achieved. In the case of the figure 2.3 plant-water relationship full irrigation is profit maximising and therefore optimal, but for the plant-water function in figure 2.1 full irrigation is not profit maximising, and therefore not optimal in the economic sense.

To restate the conclusion briefly, optimum irrigation is achieved where marginal value product is equal to marginal factor cost, or the price of water. This occurs somewhere on the positive downward-sloping section of the marginal product curve, denoted as stage II of production. Stage II is the economically relevant range of demand management. Where stage II exists, the rational farmer should respond by implementing deficit irrigation unless irrigation is completely free. Even if irrigation water is free, labour has an opportunity cost, and pumping is not free.

The fact that farmers irrigate at full irrigation levels could indicate that they, or their extension specialists, are not rational, or that over-watering is a risk minimising strategy, or it could be interpreted as evidence for the production function in figure 2.3. Clearly the economics of deficit irrigation requires further research, but it will not be addressed in the present study.

This raises the effect of whole farm analysis versus a per hectare investigation. The per-hectare case clearly suggests that deficit irrigation is the profit maximising strategy unless the underlying plant-water relationship is a linear plateau function, in which case deficit irrigation is possible, but not profit maximising, and therefore not optimal. Extending the argument to the whole farm clearly has no effect if all land is assumed to have the same quality. The farm is just a larger version of the original hectare. The result remains the same if one optimises across land of different quality and irrigation strategies.

Consider the simple case of irrigation and land as the only factors of production. Let there be four productions f^{11} which combines drip irrigation with high potential land, f^{12} which combines drip irrigation with low potential land, f^{21} which combines flood irrigation with high potential land, and f^{22} which combines flood irrigation with low potential land. Each production function has arguments water (x_1) and land (x_2). The private profit maximisation problem is:

$$\Pi = p\left(f^{11}(x_1, x_2) + f^{12}(x_1, x_2) + f^{21}(x_1, x_2) + f^{22}(x_1, x_2)\right) - w_1 x_1 - w_2 x_2 \qquad [21]$$

where

Π	farm level profit
f^{11}	drip irrigation on high potential land
f^{12}	drip irrigation on low potential land
f^{21}	flood irrigation on high potential land
f^{22}	flood irrigation on low potential land
x_1	water
x_2	land
p	product price; the firm is a price taker in the product market
w_1	water price; the firm is a price taker in the water market
w_2	land price; the firm is a price taker in the land market

The farmer optimises separately with respect to each production function, and the individual first order condition of expression [1] is:

$$\frac{\partial \Pi}{\partial x_1} = pf^{ij} - w_1 = 0 \qquad [22]$$

Since the same water can be used in any of the four production plans, the general first order condition can be rewritten as:

$$pf_1^{11} = pf_1^{12} = pf_1^{21} = pf_1^{22} = w_1 \qquad [23]$$

Expression [3] claims the marginal value product must be equal across production possibilities, but this does not imply that the same levels of water.

2.3.4.3.4. Adjusting area

If the water price goes up a smaller total area will be irrigated than before, regardless of whether water is priced volumetrically or as a flat rate per hectare (Griffin and Perry, 1985; Gaffney, 1992; Huffaker and Whittlesey, 1995). Smaller areas are grown as marginal farms go bankrupt. The more challenging question is if farmers will choose to take land out of production and maintain full irrigation on the remainder, or employ deficit irrigation on the entire area. Again the answer depends on the shape of the underlying crop-water function. The necessary first order condition for profit maximisation requires that marginal value product of water has to be equal across all fields and crops, and equal to the volumetric price of water. At a positive price for the polynomial production function, the farmer will prefer deficit irrigation across all fields to taking marginal land out of production. The optimal strategy is exactly the opposite for a linear plateau production function. Assume a linear plateau relationship, all fields and crops that yield a marginal value product higher than the volumetric price of water will be irrigated fully and all other fields will be taken out of production.

2.3.4.3.5. Crop choice

A change in the crop mix is a possible long-run response to increasing water prices. Some authors recommend switching to high value crops while others suggest water extensive crops (Gaffney, 1992; Huffaker and Whittlesey 1995; Louw and Van Schalkwyk, 1997; Worthington, 1977; Du Plessis, 1998).

Choosing high value crops is determined by factors other than water price. It may be hampered by financial, human capital and infrastructure constraints, but farmers will not choose to grow high value crops as a result of an input price increase. Rather, if the price of water rises, farmers producing low value crops will go out of business, so that is seems as if the water price caused a shift to high value crops. Faced with the possibility to go under farmers may invest in human capital or develop new skills, but the resulting production of high value crops is not directly attributable to the water price increase.

Also, when an entire region switches to high value crops, it may use more or less water, depending on the relative water use intensity and the total area. However, the marginal productivity of water used in irrigation will increase because value added per unit of water will increase relative to a low value crop.

The water saving possibility of switching to water extensive crops is apparent, but the economic rationale is much less obvious. The irrigator's problem is to maximise farm profits across crops, areas planted and irrigation strategies, as a function of input prices, output prices and production technology. If the price of water increases, the farmer may change to a crop that uses less water, or find it more profitable to plant a smaller area of this old crop. The optimal response depends on all parameters and cannot only be predicted from water prices.

2.3.4.3.6. Alternative water sources

Certain water sources may theoretically be available to a farmer but be relatively expensive to use, or of an inferior quality. When the price of the main water source increases sufficiently, alternative sources like recycling returnflows and wastewater from mines become feasible sources of water (Worthington, 1977; Du Plessis, 1998). If inferior water sources are used, the impacts of the water quality on crops and crop damage will have to be monitored carefully. Substituting superior water with inferior water for irrigation will release the good quality water for other uses, including additional irrigation.

2.3.4.4. Diverted versus consumptive use

The prior appropriation doctrine of the American West requires a distinction between consumptive and diverted use. Huffaker and Whittlesey (1995) explain the issue. Depending on the return-flow links downstream, improving on-farm irrigation efficiency may lead to an increase in water consumption rather than water conservation. If a farmer converts from an inefficient flood irrigation system (efficiency = 50%) to a more efficient drip irrigation system (efficiency = 95%), he needs to divert less water to maintain water level in the field.

True conservation is only achieved if the farmer is prevented from using his water "savings" on land that was not previously irrigated. Otherwise, more crops are grown and more evapo-transpiration implies higher water use. This argument implies that the right incentive for water conservation will encourage farmers to pursue one of the following strategies.

- plant water-saving crops, given present area and irrigation system
- reduce total area given present irrigation system and crops
- increase irrigation systems efficiency, given present area and crops

The distinction between diverted and consumptive use becomes critical when trying to incorporate environmental concerns into a unified model of water value. See, for example, Griffin and Hsu (1993), Booker and Young (1994) and Booker (1990).

2.3.5. Estimating water demand in a production setting

Colby (1986) gives an overview of production sectors and basic approaches to demand estimation in each sector. Industrial demand can be estimated in a similar manner as residential demand, or from cost data, while irrigation values are mostly imputed with programming models.

2.3.5.1. Industrial demand

Rezetti (1992) provides an example of estimating industrial water demand from cross sectional cost data. The first derivative of the cost function with respect to each input price delivers the firm's set of input demand functions. Due to data limitations it is assumed that production technology is separable in its inputs, leading to a set of weakly separable cost functions each depending on the level of output and the price of the input. Quantity of water demanded is then a function of water price and level of output. It is further assumed that the firm spends on water in one of four ways, namely intake costs, recycling costs, treatment and discharge costs and that recycling can be a substitute for intake or discharge.

The econometric model assigns elasticities to each of the four types of water. It is further assumed that the water cost function is homogeneous of degree one and that the water shares sum to unity. These constraints are imposed on the model before estimating an iterative three-stage least squares procedure and the result was an own price elasticity of demand for water intake of between –0.15 and –0.59, depending on the industry. In contrast Schneider and Whitlach (1991) estimate industrial demand as a function of a lagged quantity variable. Price elasticity of demand for industrial users was found to be of the right sign and significantly different from zero in only one of eight specifications. The corresponding long-run elasticity for this study was –1.62.

2.3.5.2. Commercial Irrigation

The standard technique used to value irrigation water is residual imputation through parametric programming. A much less common approach is to estimate marginal value product, or water demand, directly from the crop-water production functions (Colby, 1989). Few examples of this technique are published, but Botes and Oosthuizen (1994) use a similar model. Their paper relies on a crop simulator to predict water-yield responses, but replaces the programming component with a simple average production calculation similar to that used by Howe (1985). In an equally rare paper Griffin and Perry (1985) present an econometric model of irrigation demand.

The literature on programming models of irrigation farming can be divided into roughly three categories depending on the objective of the paper. The research questions are:

1. Can optimal scheduling of irrigation events (and fertiliser applications) improve total profit?

2. What is the best strategy for achieving a certain policy objective regarding water conservation (or salt loading)?

3. What is the value of (or demand for) water?

Clearly only question 3 is directly relevant to this study, but while the three strands have been quite distinct during the 1980s and 1990s, newer models are slowly re-integrating this literature.

2.3.5.2.1. Optimal scheduling models

Optimal application models try to improve total benefit by scheduling accurately during the course of an irrigation season. Modern versions use dynamic programming and often rely on crop simulators to specify crop-water relationships. The core idea is that timing matters as much in irrigation as total volume. Flinn and Musgrave's 1967 study is one of the first papers to reject a single water requirement, and instead propose a function where yield is the cumulative effect of conditions in discrete growth stages.

Cornforth and Lacewell (1982) model irrigation scheduling in a static linear programming framework. Net revenue is maximised across ten annual crops as well as pecans and lucerne for six soils and two water sources (limited surface water and unlimited saline groundwater). The model incorporates salinity effects. Possible combinations generate 1182 crop production activities. Year-to-year water balances take a block-diagonal design. The model reports water values of $8.26-$9.97 per acre-foot for full irrigation levels and finds that storing water from year to year increases net farm income by only 3 percent.

In a similar exercise Afzal et al (1992) use a static linear programming model to optimise net revenue across four crops (maize, wheat, barley, cotton), one irrigation technology and two water sources (fresh surface water and saline groundwater). The model incorporates a standard salinity damage function, in this case according to the Doornbosh-Kassam specification, and also allows deficit irrigation, which is defined as missing an irrigation event. Deficit irrigation is not profitable on all crops, but it is possible to omit four out of the last five irrigation events for cotton and still maintain profitable yields (Afzal et al, 1992).

Lefkoff and Gorelick (1990) also use linear programming but incorporate an existing hydrological model of the area to track water percolation and salt loading. The objective function maximises farm level profits across two crops (maize and lucerne) and water sources (fresh surface water and saline groundwater) subject to an area constraint, a surface water constraint and a pumping constraint. The penalty for using unlimited groundwater is introduced as a salinity damage function.

In an early application of dynamic programming in water modelling McGuckin et al (1987) optimise irrigation scheduling using a random time frame based on heat units instead of chronological time. The model accounts for stochastic weather and soil water processes, and expresses water stress as a proportion of "full irrigation" yield. Activities consist of combinations of three crops (maize, sorghum and cotton) and two irrigation systems (furrow and sprinkler). Results show that optimal scheduling improves full irrigation revenue by $10-$30 per acre.

Bryant et al (1993) include stochastic weather patterns in their dynamic programming model that optimises net revenue subject to a fixed irrigated area and a fixed number of irrigation events. The objective is to maximise net return for both crops by choosing to irrigate or not irrigate a given crop in at a given growth stage. A fixed volume of water is applied during each irrigation event. Only two crops (maize and sorghum) and a single technology (centre pivot) are modelled, but combining the crops with irrigation strategies generate 202 cropping activities, including dryland production and the option to abandon crops during droughts.

The EPIC model is used to simulate yield and irrigation data and other data were obtained from local extension agents. The model found that it is optimal (profit maximising) to irrigate the driest field any time unless maize is below wilting point, in which case maize must get priority over sorghum. The simulation does not fit reality fairly well unless crop rotation is introduced exogenously. The model shows that net revenue can be increased by 29 percent if the optimal allocation is implemented.

2.3.5.2.2. Water value models

Water value models have a completely different emphasis from optimal allocation models, and usually try to estimate water demand or value for a range of farms or under a range of water constraints. The framework of early models is typically static, but much more crop and irrigation detail is model. Later models incorporate crop simulation data and complex hydrologic relationships.

Several papers argue the feasibility of water markets by demonstrating a value differential between low value agriculture and some other high value use. Howe (1985) bases his estimate of supply on average net revenue per unit of water across crops and sub-basins of the Colorado River. Booker (1990) optimises across water use classes for the entire Colorado River, and models agricultural water use as a benefit function, but the central idea in the paper is that a value differential implies gains for trade.

Michelsen and Young (1993) investigate transfers from irrigation to municipal use and Louw and VanSchalkwyk (1997) and Grove and Oosthuizen (1997) estimate agricultural values in a South African setting. Booker and Young (1994) build on Booker (1990) and examine up-stream downstream trade-off using the same idea, but their model emphasises the salinity effects of upstream versus downstream use in the Colorado River. Taylor and Young (1995) still study the Colorado River and the possibility of transfers, but refine the irrigation dimension by including deficit irrigation. Turner and Perry (1997) provide the most recent in this suite of models, by treating instream flows as a beneficial use.

The key difference between Howe's (1985) and the other models is that the former relies on average value product as an estimate of value, while the programming models all produce shadow prices, which are measures of marginal value product. The other models focus on marginal sales, while Howe (1985) only accounts for infra-marginal changes. However, it may be more practical to sell all water rights when offered a price exceeding average net revenue instead of scaling down irrigation operations gradually. The only exception concerns what Nieuwoudt (2000) call "sleeper rights". A "sleeper right" is an unexercised water right, of which the average and marginal net revenue are zero implying that such rights will be sold at any positive price.

Booker's (1990) static linear programming model maximises net revenue across four crops (lucerne, maize, irrigated pasture and drybeans) using nine irrigation strategies that allow water-capital and water-management substitution. Booker (1990) updates Gardner and Young's (1988) linear programming model. It is assumed that lucerne fields are replanted every sixth year and crop mix is restricted to a reasonable range with an exogenous constraint. Perennial fruit is mentioned but are not modelled. Booker (1990) argues that fruit generate higher returns to water than field crops, and that model results therefore represent a lower bound of agricultural values. Shadow prices generated through parametric programming show water values of \$6-\$65 per acre-foot. The salinity constraint takes the form of a simple salt balance and defines return-flows as the difference between diversion and average consumptive use for the area. Parametric programming of the salt constraint produces salt values of \$6.10-\$11.00 per acre-foot.

Michelsen and Young's (1993) model maximises net revenue and accounts for four crops (maize, lucerne, dry beans and barley) and two irrigation systems (furrow and flood). It also includes dryland lucerne. The typical exogenous range on crop mix is used in this case and the model incorporates a stochastic river flow component to simulate droughts. Results show an offer price \$85 per acre-foot, clearly suggesting gains from trades with Denver that is considering supply options costing \$4 000 per acre-foot.

Louw and VanSchalkwyk (1997) represent a South African example of a straightforward valuation model. The model maximises the present value of farm profits while accounting for overhead costs, household living expenses (of R100 000 per year), interest and capital repayments. Deficit irrigation is included but the crop-water function is not reported in the article. The model includes orchards by assuming a fixed age distribution and modelling three age categories as separate activities. Non-bearing trees are constrained as a fixed proportion of bearing orchards and the model includes a constraint on high value crops. Water demand was derived through parametric programming of a water constraint.

Louw and Van Schalkwyk's paper differ from rest of the literature in terms of their definition of water value. It calculates a water value by taking the difference between total profit with irrigation and total profit without irrigation expressed as a value per unit water applied, instead of the standard shadow price on the binding water constraint. The

Louw and Van Schalkwyk definition of water value is an average water value product, rather than the more appropriate marginal value product.

Once again, the amount by which this specification over-estimates marginal water value depends on the underlying production function. If the underlying relationship is the polynomial function of figure 2.1 average product overestimates marginal value product, but if the crop water function is a linear plateau, average value product is equal to marginal value product. Since Louw and Van Schalkwyk's 1997 study is a farm-level analysis, the plant-water relationship may be linear plateau for individual fields but the model allows for different crop-irrigation combination which suggest that the average and marginal value of water falls as more water is applied. By calculating an average value product in such a setting these authors overestimate the amount farmers are willing to pay for water at the margin.

From the middle 1990s onwards the hydrology component of standard water value models have gradually become more complex. Griffen and Hsu (1993) give a theoretical treatment of the problem of incorporating instream users. The model recognises instream flows, consumption and diversion separately, and establishes the relationships between consumptive use and diversions. The paper concludes that tradable rights have to be extended to consumptive use and identifies returnflow coefficients as a key element necessary to fully specify water rights.

Booker and Young (1994) examine water values by comparing up- and downstream irrigation, municipal use, industrial use and hydropower in a detailed hydrological framework for the Colorado River. The model accounts for salinity and maximises net economic surplus across all uses. Upstream and downstream irrigation and hydroelectricity are modelled as benefit functions while municipal demand and interbasin transfers are assumed fixed. Irrigation demand in the lower basin represents 13 crops on two soil types for high (1 100ppm) and low (800ppm) salinity. Upper basin irrigation models four crops with nine irrigation strategies. The volume of deep percolation, which depends on the irrigation technology, determines the amount of salt loading. Benefits to hydropower generated are modelled as the marginal cost avoided.

Booker and Young (1994) analyse six institutional scenarios involving various marketing arrangements. Under the status quo the downstream constraint is binding, generating municipal water values of $300 per acre-foot. Restricting trades to the state of California reallocates water from low value irrigation to high value irrigation and municipal use. When trade is allowed across state boundaries, upstream agriculture releases water to downstream users. The opportunity cost of water to high value irrigation ranges between $18 and $19 per acre-foot. Redistribution within California and across states increases total benefit as expected. The total loss to agriculture is much lower in the second case, because removing a structural transfer constraint allows low value irrigation upstream to be accessed first.

Taylor and Young (1995) combine the standard valuation model with some aspects of the allocation literature. The paper models crop production in stages, with decisions being revised in every stage as new information becomes available. It maximises expected regional income across three crops (maize, lucerne and sorghum), four soil types, three irrigation strategies and two water supply scenarios. As in the case of Afzal et al (1992) deficit irrigation is defined as omitting an irrigation event, rather than applying smaller volumes. Crop rotation is an exogenous constraint. Model validation matched results to observed crop distribution. Apart from introducing stochastic weather, the model is interesting because it examines a scenario where farmers plant before they know how much water will be available per ditch share.

Turner and Perry (1997) use stochastic linear programming with recourse to estimate irrigation demand for a single representative farm in two districts. The model maximises profits across seven typical crops (irrigated pasture and grass hay, lucerne, wheat, peppermint oil, carrot seed, garlic seed and bluegrass seed) and 16 types of irrigation equipment ranging from basic flood technology to centre pivots. Each technology is modelled with and without scheduling which is assumed to improve systems efficiency by 10 percent and reduce deep percolation by 5 percent. The water constraint is modelled as a mean water delivery of particular probability, where probability of delivery is expressed as years out of ten when more or less of the mean is available.

Turner and Perry (1997) specifically mention the notion of Ricardian rents, and isolates water values as the residual after all other fixed factors have been compensated at opportunity cost. Risk is treated as a farm-level fixed cost, and rental values in the area were used as a proxy for land rents. Fixed costs are not awarded on a per hectare basis, but proportional to gross income. This way of modelling fixed costs is more flexible than either modelling total fixed costs as a farm-level constraint, or modelling it on a per hectare basis. It is argued that the entire residual accrues to water, because the alternative to production is extensive grazing. It is reported that a third of the instream flow required could be purchased at $25 per acre-foot when farmers stop producing fodder crops namely lucerne, grass hay and irrigated pasture. Links to livestock operations in the area are not explored. At offer prices of $70-75 per acre-foot all irrigation activities are suspended in the one district. In the other district seed production produces water opportunity costs of about $140 per acre-foot.

At least three papers combine stochastic weather, with or without dynamic optimisation, with plant simulators to estimate water values. Bernardo et al (1993) present the theoretical framework, and Dinar et al (1993) provide an application. Grove and Oosthuizen (1997) apply this framework to a South African situation.

Bernardo et al (1993) integrate a crop simulator and regional optimisation model to examine the impacts of water quality regulations. Crop simulation provides input into a programming model, which in turn maximises net benefit subject to a set of hydrologic constraints. The programming model consists of production activities, irrigation investment decisions, product sales and input purchases and accounting activities that keep track of chemicals in the root zone and groundwater for homogenous "agroecoregions". Exogenous constraints govern irrigation technology adoption to prevent unrealistically large changes in a single year, and thereby approximate some capital constraint in practice. Capital depreciation of irrigation systems is modelled as a lower limit on the process of converting from water using to water saving irrigation technology. The crop simulator is EPIC-PST and groundwater simulator is MODFLOW. Pesticide use is emphasised to evaluate water quality impacts.

Dinar et al (1993) use dynamic optimisation to maximise net revenue by choosing optimal irrigation and crops but instead of the traditional crop simulator data this model uses lysimeter field data. The model incorporates multiple sources and qualities of water and permits a water marketing activity. Three crops are included (wheat, sorghum and irrigated pasture) but irrigation technologies are modelled as separate experiments. The policy options considered are water taxes, direct effluent taxes (Pigovian tax) and technology subsidies. Two results are particularly interesting. First, a subsidy of 60 percent of capital cost is necessary to make farmers indifferent between flood and sprinkler technology. Secondly, while Pigovian taxes are more effective and cost efficient than targeting irrigation water, the difference is negligible, suggesting that the more straightforward procedure is the appropriate policy intervention.

Grove and Oosthuizen (1997) investigate the effects of deficit irrigation and improving irrigation systems efficiency. The objective function maximises net income in a chance-constrained linear programming model. Water stress is modelled as yield reduction of the Doornbos-Kassam type. A maximum water reduction of 20 percent was allowed. Supply conditions are varied parameterically and returnflows are calculated ex post, by assuming that roughly half of non-consumptive use can be used downstream. The paper reports a base value of returns to water and other fixed factors of R3 943.70/ha. Improving systems efficiency from 67 percent to 75 percent increases gross margin by R55.70 per hectare and the authors conclude that this the upper bound on private expenditure to improve systems efficiency.

Three other papers in literature on water value models are worth mentioning. Mallawaarachchi et al (1992) model permanent crops, Onal et al (1998) examine equitable distribution of impacts, and Teague et al (1997) study environmental risk and compliance levels.

Mallawaarachchi et al (1992) indirectly estimate water values to fruit farmers in Australia by exploring optimal investment decisions. The region is modelled as a single representative farm with citrus and wine grapes in yearly age categories. The model chooses between furrow and drip irrigation and includes activities to borrow and invest off-farm and take off-farm employment. The paper is unique in that it endogenises replant and irrigation technology adoption decisions. The model maximises terminal value of a 20-year investment period, which is equivalent to maximising net present value (Mallawaarachchi et al, 1992). Results show that the decision to switch from furrow to drip irrigation is taken to avoid water cost, or where the opportunity exists to expand the area under fruit so that water becomes a binding constraint. The model does not account for fruit quality differences due to different irrigation practices.

Onal et al (1998) do not directly model irrigation, but focuses on the run-off from arable land. The paper is interesting is unique in insofar as it imposes a minimum variability in economic loss across farmers, so that the cost of a given policy is equitably distributed across participants. An equal sharing of losses is defined as the (perfectly) equitable solution while zero equity is defined where a single person bears all the costs and everybody else continues as before. The model is a change-constrained programming model that maximises a margin above certain variable costs subject to the normal constraints. It includes a stochastic variable representing atrazine leaching to a nearby reservoir.

Teague et al (1997) examine various levels of compliance with nitrate and pesticide regulation by modifying the target MOTAD procedure that is sometimes used to introduce income risk into a linear programming formulation. The standard target MOTAD formulation sets a target income and varies a risk aversion coefficient parametrically. Completely analogous, in this model a target level of nitrate or pesticide leaching is set, around which a compliance coefficient is varied. This environmental risk aversion parameter is interpreted as "the acceptable level of compliance with the target", and the magnitude of the coefficient indicates how much more pesticide or nitrate leaching than the specified target a farm produces.

The paper points out that stochastic measures of environmental risk are important, because while expected leaching may be low, a large loading event may be disastrous. The model accounts for three crops (maize, wheat, and sorghum) in various rotations on two soil types (clay loam and sandy loam) allowing three kinds of irrigation (furrow, centre pivot and dryland). In the nitrate leaching experiment, tightened of the compliance constraint increases wheat over sorghum, while maize is switched from the light soil to the heavy soil to reduce leaching. When the nitrate target is strictly enforced, total planted area shrinks compared to the status quo, but all irrigated land remains in production. Pesticide experiment shows similar shifts in crop patterns, but in general meeting pesticide targets comes at a smaller income reduction than meeting nitrate targets.

2.3.5.2.3. Policy evaluation models

The most frequently modelled policy issues are water conservation, salt loading of returnflows and pesticide leaching, and the most regularly encountered policy instruments are quotas, taxes and technology subsidies. Compared to the optimal application models policy models have simpler hydrologic and soil specifications but cover a more realistic range of crops and irrigation technologies.

Gardner and Young (1988) model the trade-off between upstream cost of avoiding salinity and the downstream benefits of lower salinity levels by measuring the benefits foregone to upstream irrigation if salinity is reduced. A linear model maximises annual net returns to fixed resources, land and water for the region as a whole. Activities combine five crops (lucerne, barley, maize, pasture, drybeans) and ten irrigation strategies that account for a range of technology and management options. The analysis takes a long-run perspective and allows technology substitution. The policy options examined are technology subsidies, a hypothetical tax of salt discharges and taxing irrigation water. The results show that direct salt charges achieve salt reduction at lower cost than subsidising irrigation equipment or increasing water price. In fact, raising the water price is an expensive and relatively unsuccessful strategy to reduce salt loading.

Johnson et al (1991) integrate a crop simulation model, a dynamic optimisation model and a linear programming model to evaluate farm-level economic impacts of reducing nitrate leaching associated with irrigation. Data from the CERES plant simulator feed into a dynamic optimisation routine that schedules irrigation and fertiliser application, similar to that reported by McGuckin et al (1987) and Bryant et al (1993). A linear programming model then uses these results to maximise farm profits subject to additional crop rotation and institutional constraints. Fertiliser and irrigation costs are the only variable costs. Optimal timing improves profits between 3 and 9 percent for wheat, maize and potatoes. Policy scenarios show erratic results, but Pigovian taxes are consistently the most cost-effective way to reduce nitrate leaching. Simulated abatement costs were the highest on potatoes, and the lowest on maize.

Lee and Howitt (1996) present a policy model with a slightly different emphasis. It relies on production functions estimated from price data including shadow prices for water generated with a linear programming model. The basic production was further adjusted with the standard Maas-Hoffman type damage functions to allow for salinity impacts on crop yield. The optimisation routine integrates upstream salinity abatement costs and downstream benefits of lower salinity in a hydrology framework.

The model maximises net returns across all uses by choosing land, the size and timing of irrigation events, and Federal programs. Eight crops are modelled, namely lucerne, barley, grain and silage maize, wheat, grass hay, cotton and oats. Municipal and industrial benefits were modelled as linear functions of salinity and control costs include federal projects and management alternatives. Policy alternatives considered are reducing water applied, changing to crops that require less water and retiring land from production. None of the strategies achieve a reduction in salt levels without cost to upstream users. Federal salinity projects reduce salt loads efficiently, but not in a cost-effective way. It is much cheaper to combine federal projects with a combination of Federal Programmes and water conservation measures, and by eventually shutting down upper basin production down completely.

2.3.5.3. Small-scale irrigation in traditional communities

In rural South Africa tribal irrigation is an important potential user category, even if it claims a small percentage of the total irrigated area. The literature contains very few examples of linear programming models that include commercial or subsistence smallholdings. Several studies document the performance of small-scale irrigators in South Africa, but no attempts have been made to include tribal irrigators in a regional programming model. Hazlewood and Livingstone (1982) describe a linear programming model that solves for the optimal mix of smallholdings and large commercial farms. Compared to large commercial units the small-scale farms are not efficient users of water, but it is shown that introducing small-scale farmers improves total systems efficiency. Hazlewood and Livingstone (1982) argue that small-scale farmers use traditional cultivation methods that generally fits better with resource constraints.

Hazlewood and Livingstone (1982) model commercial smallholdings that compare directly to large-scale commercial farms. However, small-scale subsistence plots are conceptually no different from commercial smallholdings as long as home-consumption is valued at the appropriate opportunity cost (Gittinger, 1982). In the South African setting it is helpful not to have to distinguish between commercial and subsistence smallholdings, since the difference is seldom clear. In most cases farmers produce primarily for home-consumption and sell the surplus. Chapter 7 treats smallholders as a single group, since households farming "commercial" smallholdings also consume most of what they produce (Van Averbeke et al, 1998).

2.4. Demand management and the environmental reserve

South Africa is one of the first countries in the world to legalise its recognition of the environment as a priority water user. The National Water Act (Act 36 of 1998) reserves an unspecified portion of the instream flow in each basin to ensure sustained ecological services (Republic of South Africa, 1998).

It is generally accepted that while instream flows are not a consumptive use in the strict sense of the word it needs to be treated as the equivalent of a consumptive use, because it is not available for diversion (Colby, 1990; Frederiksen, 1996). Moreover, by awarding it legal priority the National Water Act (Act 36 of 1998) removes any need to place a value on the environmental reserve. However, the theory of environmental values provides useful insights about the optimal size of the environmental reserve. The value of instream flow has many components. At the very least it provides assimilative capacity that reduces water treatment costs (Colby, 1990). Also generally recognised is the water quality benefit to recreation and its secondary impacts in the local economy. The third component of instream values is nonuser values (bequest, option and existence) that accrue to people who may never directly use the stream.

Giraldez and Fox (1995) give an example of how non-market values affect the value, and hence the optimal size of the reserve. The estimated cost of groundwater nitrate pollution in Southern Ontario vary by a factor of 100 depending on which non-market values are included. A conservative estimate of pollution costs value nitrate pollution at between $693 and $6 289, while a contingent valuation method study including option and bequest values estimates willingness-to-pay for safe drinking water at between $29 938 and $700 000 per year. Clearly non-use values inflate that environmental worth compared to use values.

It is clear from the example above that the challenge is not to illustrate that non-use values contribute significantly to environmental benefits, but rather to achieve a fair and sustainable trade-off between diverting water and keeping it instream. It is all too easy to show that allocative efficiency is achieved when all water is left instream, but this view does not fully acknowledge the opportunity cost of removing water from present production to return to the river as an environmental reserve where rivers are already fully appropriated.

South Africa's environmental reserves will be implemented in four stages. The first stage is a desktop study of mostly hydrology and the final phase involves a comprehensive study of river ecology and includes stakeholder participation. The favoured methodology for estimating the comprehensive reserve is the building block method (Tharme and King, 1998). According to this method, flow requirements in a river is separated into four components (building blocks) each of which has to be satisfied to maintain the integrity of the environment.

In practice the recommended reserve is tied to a management class. Rivers in management class A are pristine while class D rivers are regarded as "workhorse" rivers of which the environmental integrity has already been compromised. It is expected that the entire reserve estimation process will take two to four years per river. Regardless of the way in which rivers are prioritised, it will take a substantial period of time before ecological studies have been completed for all rivers.

Due to the transfer scheme the situation in the Great Fish and Sundays Rivers are more complex than in many other rivers. Flows in these rivers have been changed completely by the interbasin transfer and expert opinion indicates that chances of the rivers returning to pre-transfer conditions are slim. For example, in a study of river ecosystems it was found that more than 40 percent of the indigenous invertebrate species in the Great Fish River have disappeared following the introduction of constant flows (Davies et al, 1994). Also five fish species were introduced through the tunnel.

The recorded changes have important implications. The observed changes do not imply that the hydrological and ecological conditions created by the transfer scheme are unsustainable, but only that the river can no longer be regarded as pristine in the original sense of the world. The Great Fish River, for example, has to be considered as a "work horse" river and environmental reserve defined for it will hopefully reflect this reality.

2.5. Previous research in the Fish-Sundays region

None of the models described in section 2.3.5 have been adapted to the Fish-Sundays scheme, but the following studies were useful in developing a linear model of irrigation in the region within hydrological and reserve constraints.

2.5.1. Description of hydrological conditions

There are two hydrological models of the Fish-Sundays scheme available. The Fissun operational model supports a week-to-week management of the scheme. It seeks to "maximise operational efficiency with particular regard to water quality by making the minimal use of freshening water to achieve a desired salinity target" at the bottom of the system (Tylcoat et al, undated). The Fissun model is a mass balance model with a daily time-step and two-week horizon that predicts salinity levels per node based on stored water, inflows, diversions, rain and returnflows. Model documentation summarises nodes and assumptions on magnitude and salinity of returnflows and tributary flows. Data on total diversions per node used as model input is stored for one year.

Basson (1999) describes the Fish-Sundays scheme and includes a current (based on 1994 requirements) and 30-year projected water balance for the region set in the national context. Chapter 3 describes and incorporates Basson's analysis.

2.5.2. Demand functions and water values

Water demand functions have not been estimated for any user category, but some preparatory work has been done for agriculture. The most comprehensive of the agricultural studies reports on the financial viability of irrigation farming along the Great Fish River (Backeberg, 1984). The study covers three sub-regions and two farm classes, but does not estimate water demand specifically. These calculations were repeated from time to time by the Department of Agriculture. No recent work describing the economics of irrigation has been published for the Sundays River. A set of enterprise budgets are available for the Eastern Cape, but the 1999 collection does not include any enterprise budgets for the irrigated areas of the Fish and Sundays River (Els, 1999). Municipal water demand has not been estimated for Port Elizabeth to date and the only environmental constraint on systems operations is a special dry period for blackfly control in July (Palmer, 1997).

2.6. Conclusions for model specification

Chapter 2 revealed that municipal water demand can be managed partly through price, and that farmers will respond in a variety of ways to price increases. It was shown that marginal cost pricing ensures allocative efficiency under perfect competition and that average cost pricing does not apply when the demand management is called for. Marginal cost pricing will have to be implemented on a volumetric basis, but there is ample evidence that markets achieve superior allocation results compared to administrative pricing systems.

A review of possible farmer responses to price increases indicate that a realistic model of irrigation should include an appropriate range of crops, allow for water-capital substitution and water-labour substitution. It should also allow land to be taken out of production. Deficit irrigation is an interesting case with some theoretical justification, but in practice very little deficit irrigation is observed. Chapter 2 showed that the most commonly used plant-water relationships leave little opportunity for deficit irrigation. Finally, while not pertinent in the South African context, it will be interesting to consider the difference between diverted and consumptive use as a basis for reallocation.

CHAPTER 3: WATER BALANCE: THE STUDY IN CONTEXT

3.1. Introduction

In a study of basin-wide water values, reviewing a water balance for the basin of interest provides a hydrological framework that places the economic analysis that follows in a historical and institutional context. A recent hydrological systems analysis by Basson (1999) published by the Department of Water Affairs and Forestry provides a useful national context for the Fish-Sundays transfer scheme. The central conclusion of Orange River Development Project study is:

> "The comparison on a national basis of the economic production per unit of water for different sectors of the economy, considering both direct and indirect effects related to water use, showed that the agricultural sector utilises substantially more water per unit output and creates far less employment per unit of water than any other sector. A further comparison of the economic benefits of allocating water to irrigation in the Orange and Fish/Sundays region and the benefits achievable by applying the same volumes of water to a diversified and industrialised economy such as Gauteng, showed the economic production and employment opportunities per unit of water in the latter region also to be far greater".
>
> Basson, 1999

Basson's conclusion speaks for itself and is consistent with the notion of reallocation to achieve economic efficiency. The critical questions are when we can expect water to become a binding constraint, and specifically how limited supplies in the Orange River system will affect the magnitude of transfers to the Fish-Sundays scheme. Chapter 3 attempts to answer this question by first defining the scheme and providing a short history of water use, and then presenting the chief results of the Orange River study as summarised by Basson (1999). The chapter closes by placing the Fish-Sundays scheme in its Orange River context in order to highlight the implications for demand management.

3.2. Components of the transfer scheme

The scheme comprises the Great Fish and parts of the Sundays River in South Africa. The Orange River Development Project Act (Act 78 of 1969) proclaims the transfer scheme as those river reaches serviced by water from the Orange River. The present study follows Basson's 1999 example by restricting analysis only to the transfer scheme.

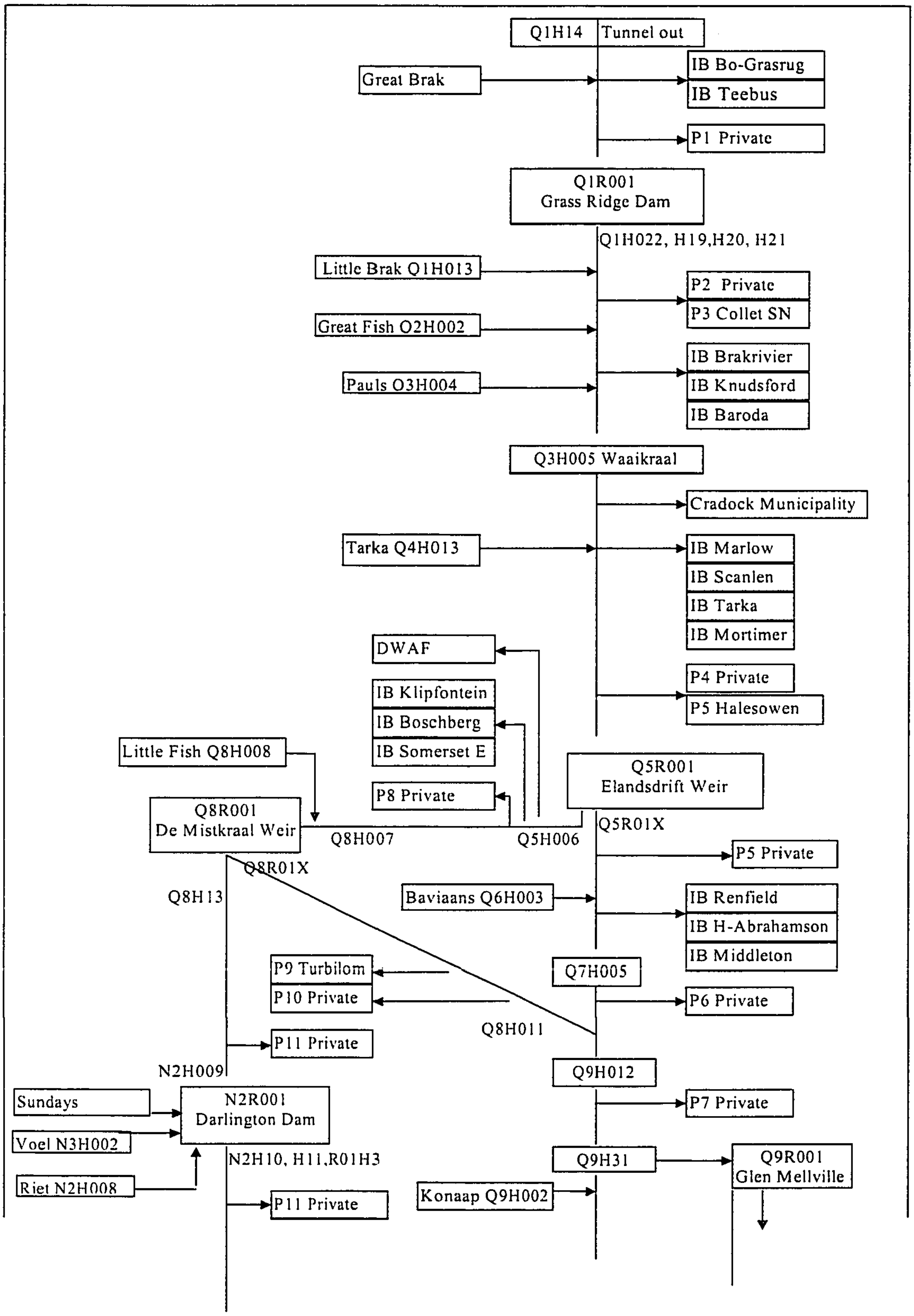


Figure 3.1: Detailed layout of the Fish-Sundays scheme

Figure 3.1 illustrates that the rivers are not separate entities but form part of a network of canals, which is supplied almost entirely from the adjacent Orange River basin at a rate of 560 million m^3/year. The Fish-Sundays scheme consists of three Government Water Schemes proclaimed in terms of the Water Act (Act 54 of 1956). In the north the Great Fish River Government Water Scheme supplies irrigators on the banks of the Great Fish and Little Fish Rivers between Steynsburg in the north and Middleton in the south. To the south-east the Lower Fish Government Water Scheme provides water to Grahamstown and a small amount of tribal and commercial irrigation in the area. To the south-west, on the Sundays River, the Lower Sundays River Government Water Scheme supplies water to irrigators between Kirkwood and Barkley Bridge, and the City of Port Elizabeth (Secretary of Water Affairs, 1986).

Analysis of the Lower Fish Government Water Scheme is restricted to tribal irrigation. The background, results and water values of tribal irrigation are reported in Chapter 7. The model of commercial irrigation is based the Great Fish and Sundays Government Water Schemes, with the latter referred to as the "Sundays" region and treated as a single region of analysis. The Great Fish Government Water Scheme covers a much larger and more diverse area than the Sundays Government Water Scheme. The Great Fish Government Water Scheme is locally organised into an upper, middle and lower district, which are used as three additional regions of analysis.

Boundaries for the three Fish River regions present a possible source of confusion. Lacking a comprehensive data set on which to base objective classification, the town where most farmers conduct their business is used as a basis for dividing the district. Somerset East services the Lower district, Cradock the Middle Fish and Middelburg the Upper Fish.

The boundary between the Lower and Middle Fish is clear and widely agreed upon. The area south of Elandsdrift Dam up to Middleton comprises the Lower Fish, while Mortimer farmers just north of Elandsdrift Dam use Cradock as their main service centre. Backeberg (1984) - amongst others - defines Elandsdrift Dam as the boundary between the Middle and Lower Fish.

The transition from the Middle to Upper Fish is more gradual and therefore more problematic. In Backeberg's (1984) study Cradock is used as boundary, but subsequently the scheme was extended to the north into a different microclimate and magisterial district, so that Cradock no longer serves as an appropriate break. The present study defines the Upper Fish as Teebus and BoGrasrug Irrigation Boards, and includes Backeberg's 1984 Upper Fish (Knutsford and Baroda Irrigation Boards) as part of the Middle Fish. The district boundaries are consistent with those used by the Great Fish River Irrigation Board.

A second potential source of confusion is the distinction between the Little Fish River, which is a tributary of the Great Fish River, and the Great Fish (or Fish) River. The Little

Fish River forms part of the transfer network to the Sundays River. Most sources refers explicitly to the "Little Fish", where appropriate, while "Great Fish" and "Fish" are used interchangeably to indicate the Great Fish River. The same approach is used here.

Finally, whilst the irrigated area south of Kirkwood on the Sundays River is strictly speaking located on the Lower Sundays River, this terminology is not used amongst local farmers. Rather, they refer to the immediate surroundings of Kirkwood as the "upper valley" and to the area around Addo as the "lower valley". In this report "Sundays" refers to the entire area between Kirkwood and the ocean.

3.3. History of irrigation development

White settlement of the Fish and Sundays basins took place during the early part of the 19^{th} century. Black tribes already occupied the area when the first white farmers arrived, but early tribal irrigation is not recorded in the sources consulted. Complete irrigation histories of the Fish River and Sundays River valley are given in Els (1965) and Delport (1987) respectively and other briefer accounts are found in Van Heerden and De Kock (1980), Backeberg (1984), and Van Veelen and Stoffberg (1987). In addition, nine supplementary reports on the Orange River Project by various Secretaries of Water Affairs from 1964 to 1990 trace out the history of scheme construction and Dyke and Murray (1997) provide the most recent review of irrigation in the area. Selected events are summarised in table 3.1.

3.3.1. Pre-transfer irrigation

The typical irrigation farm of the 19^{th} century was a small-scale operation producing non-perishables such as grain, brandy and wine (Van Heerden and De Kock, 1980). Nonetheless an irrigated area of 23 600 ha was scheduled along the Fish River by 1921 (Van Veelen and Stoffberg, 1987). Els (1965) reports the presence of a fruit industry in the Lower Fish which at its peak produced a crop of 300 000ton, employed 3 000 people and accounted for 75 percent of irrigated land in the area. Wool replaced fruit during World War II when it was difficult to ship fresh produce to Europe and wool was needed for the war effort. Backeberg (1984) describes a resilient system that combines an irrigation element with extensive livestock farming.

Delport (1987) gives a detailed account of irrigation development along the Sundays River starting with the first settlement in 1814, and tracing through various private initiatives, including Sir Percy Fitzpatrick's Cape Sundays River Settlements Company. The first fruit trees were planted in 1883 and the first citrus trees were planted in 1908 and exported to England shortly afterwards.

Table 3.1 was compiled from Backberg (1984), Delport (1987), Van Veelen and Stoffberg (1987) and the records of the Irrigation Boards. It lists the important construction events and proclamation dates of selected irrigation boards. Table 3.1 shows the establishment of formal irrigation in the early part of the 20th century and a flurry of construction in the 1920s.The 1960s and early 1970s were characterised by irrigation problems, which eventually led to the Fish-Sundays transfer scheme in 1978. The problems were rapid silting of Grass Ridge, Kommando Drift, Lake Arthur and Darlington (Lake Mentz) Dams, which that rights from the local rivers became over-appropriated resource. For example, in the summer of 1945/46 Grass Ridge Dam delivered only 12 mm/ha scheduled and Lake Arthur could supply a mere 75 mm/ha scheduled compared to the present allocation of 1 350 mm/ha (Van Veelen and Stoffberg, 1987). As recently as 1970/1971 Darlington Dam was empty for six months (Delport, 1987).

Table 3.1: Selected construction and board proclamation dates in the Fish-Sundays

Date	Development
1909	Tarkabrug Irrigation Board on Fish River
1911	Korhaansdrift weir on Sundays River
1911-1912	Scanlen and Baroda Irrigation Boards proclaimed
1917-1922	Sundays River Irrigation Board established and construction of Darlington Dam (Lake Mentz) began
1921-1923	Grass Ridge Dam on the Great Fish
1921-1925	Lake Arthur on Tarka River
1922	Baroda, Tarkabrug, Mortimer, Klipfontein, Hougham-Abrahmson and Middleton canals constructed on the Fish
1923	Marlow, Scanlen and Renfield canals constructed on the Fish
1952-1957	Kommandodrift Dam on the Tarka
1961-1962	ORP proposed and stage I accepted
1961 and 1966	Land de-scheduled along the Fish
1970-1971	Darlington Dam empty for 6 months
1975	Orange Fish Tunnel completed
1978	Pumped transfer to Sunday River at Wellington Grove
1986	Lower Fish Government Water Scheme proclaimed
1985-1992	De Mistkraal weir constructed upstream from Wellington Grove for gravity transfer to Sundays River; canal improvements and supply to Port Elizabeth on Sundays River GWS
1993	Tarka scheme supplied from Fish-Sundays scheme

Table 3.1 also lists major construction events of the inter-basin transfer, starting with tunnel construction in 1995. The Fish-Sundays scheme has gradually expanded during the late 1970s and 1980s. The last major extension happened in 1993.

3.3.2. The Orange River Project

The original proposal for the Orange River Development Project emphasises supply-side management and irrigation development (Secretary of Water Affairs, 1962). Lacking sufficient arable land downstream of the main reservoirs on the Orange River, a transfer scheme to the Eastern Cape was included in the proposal.

> "It is possible to lead part of the water through the watershed to the valleys of the Great Fish and Sundays Rivers, where an urgent need for supplementary water supplies exist. There are also large areas of irrigable and developed land in these valleys which can be brought under irrigation."
>
> Secretary for Water Affairs, 1962

Apart from irrigation development various other benefits including urban water supplies, flood control, recreation facilities and generating hydroelectric power were anticipated for the Orange River Project. Indirect benefits such as employment during construction, as well as on irrigation projects and through industrial development following additional agricultural production, were also anticipated.

The 1962 plan outlines a project in five stages, of which stage I includes a tunnel to the Fish-Sundays scheme. An extensive distribution network to supply irrigation developments around Cradock and south of Kirkwood that were developed in the first half of the twentieth century was also planned for later stages (Secretary of Water Affairs, 1962). A further canal system was planned to service the Upper Sundays River near Graaff-Reinet, but was never constructed (Secretary of Water Affairs, 1971).

Construction on the Orange-Fish tunnel started in 1966. The Gariep Dam was completed in 1971 and the Orange Fish Tunnel was officially opened in 1975. The first water reached Cradock in 1977 and Kirkwood in 1978 (Secretary for Water Affairs, 1984). Latent salinity problems emerged during an exceptionally wet cycle in the mid 1970s, which caused extensive damage to citrus orchards (Viljoen et al, undated). To dilute poor quality local water additional capacity was created in the Sundays scheme in 1986 and the capacity of the canal network was increased in 1992. In addition, an off-stream reservoir was built near Grahamstown and the Lower Sundays Government Water Scheme was extended to incorporate a connection to Port Elizabeth in the early 1990s (Secretary of Water Affairs, 1990).

The typical farming system in the Fish region consists of fodder crop production that is integrated to varying degrees with livestock systems. Farm size determines the extent of the interaction in most cases, but in general irrigation is practised on an extensive basis. In contrast the Sundays River is characterised by intensive citrus production on smaller farms. Most farms do not have a livestock enterprise. Chapter 5 provides a detailed description of current farming systems in the Fish-Sundays scheme.

3.4. Water balance for the Fish-Sundays scheme

Table 3.2 compares a 1994 and 30-year projected water balance for the Fish-Sundays transfer scheme taken from Basson (1999). Appendix 3.1 provides the Department of Water Affairs and Forestry's planning balance on which reserve calculations are based. The planning balance covers the entire basins, and therefore overstates requirements and resources for the transfer scheme. However, it is interesting to note that the planning balance estimates total 1995 requirements at a one in fifty year assurance level to be just under 800 million m^3/year, while Basson (1999) calculates a total requirement of approximately 586 million m^3/year at about the same point in time. Despite the higher estimate of present requirements, the planning balance still indicates an unclaimed yield of just over 80 million m^3/year, suggesting a best case scenario where the system can still grow by approximately 10 percent of 1995 levels.

Table 3.2: Water balance for the Fish-Sundays scheme

Requirements and sources	1994 (million m^3/year)	2030 (million m^3/year)
Losses & environment	–	–
Human reserve & associated stock watering	–	–
Urban/industrial/mining	16	65
Irrigation	570	645
Total requirements	**586**	**710**
Transfer from Orange	560	684
Firm yield local sources	4	4
Further yield supported by transfer	22	22
Total sources	**586**	**710**

Source: Basson (1999)

In Basson's case the transfer volume closes the balance, after requirements are partly supplied from local sources. Presently the Great Fish and Sundays Rivers and their main tributaries contribute less than 5 percent of water required by municipal use and irrigation, and by 2030 the Fish and Sundays Rivers will supply just over 3.5 percent of what is required. The present transfer volume is expected to increase from 560 million m^3/year to 864 million m^3/year by 2030 as a result of growing municipal demand. Basson (1999) assumes irrigation to remain at present levels for the next three decades.

Tylcoat et al (1990) state that systems losses are a function of management, and that "[l]osses ... will be in excess of 15% and with incorrect operation could easily amount to 40% and more ...". The planning balance assumes an overall river loss of 112 million m^3/year, which may or may not be acceptable given the 800 km river channel that forms the main distribution line. Moreover, Stassen et al (1997) estimate that farmers lose between 10 and 20 percent of their allocation due to water orders that cannot be cancelled in time in response to rain.

3.4.1. Water sources

Basson's 1999 water balance for the scheme is based on Stassen et al's simulation of naturalised flows for the Great Fish and Sundays Rivers published in 1997. The simulation uses Water Resource90 rainfall data and evaporation data obtained from the Department of Water Affairs and Forestry. Average rainfall for the area is between 300 and 400mm/year with precipitation increasing in a south-easterly direction and potential evaporation rising from about 1200mm/year on the coast to about 1800mm/year in the headwaters of both basins (Midgley et al, 1994; Basson, 1999).

One of the hydrological characteristics is that flows are highly variable, with standard deviations often exceeding mean flows. A mean naturalised streamflow of 206 million m^3/year and a standard deviation of 184 million m^3/year is recorded for the period 1923 to 1977 at Darlington Dam (Midgley et al, 1994). The simulated cumulative flow for the Sundays River basin is 244 million m^3/year and the standard deviation is 279 million m^3/year. The Great Fish River's mean naturalised streamflow is estimated to be 448 million m^3/year, and the associated standard deviation is 537 million m^3/year. Basson (1999) estimates a firm yield of only 4 million m^3/year when the Fish-Sundays scheme is operated in isolation from the Orange River.

Table 3.3 confirms the extreme variability of tributary flows and their small overall contribution. The average transfer volume between 1993/94 and 1997/98 was 534.42 million m^3/year, about 95 percent of Basson's estimated transfer of 560 million m^3/year. An all time high of 650 million m^3/year was transferred into the Fish-Sundays scheme in 1997/98 at a time when local flows were at a five-year low.

Table 3.3: Tributary flows and transfer volumes in the Fish-Sundays scheme

	1993/94	1994/95	1995/96	1996/97	1997/98
	million m^3/year				
Little Brak	0.17	0.00	0.03	0.00	0.00
Great Fish	25.84	2.20	4.81	19.80	4.13
Pauls	4.89	3.31	4.82	29.88	4.14
Tarka	5.77	9.42	10.60	15.20	12.83
Baviaans	9.27	37.56	7.27	38.25	1.63
Little Fish	24.69	25.56	14.40	59.16	10.06
Sundays	23.70	16.10	13.10	101.00	2.19
Riet	2.06	2.22	0.76	7.01	0.03
Total tributaries	96.39	96.37	55.79	270.30	35.01
Transfer volume	446.37	538.55	528.41	508.27	650.51

Source: Hydrology database, DWAF

3.4.2. User categories

The user categories considered are the environmental requirement, irrigation, municipal demand, rural demand by previously disadvantaged communities, and systems losses. Stassen et al (1997) account for municipal use, irrigation, systems losses, and water quality requirements. Municipal use is treated as the highest priority, but within the category Port Elizabeth is assumed to be more junior than other towns in the region, possibly because the city has access to significant other supplies. Basson (1999) adds a human reserve and associated stock watering to the list and prioritises the ecological requirement over municipal demand.

3.4.2.1. Environmental requirement

Basson (1999) defines the Orange River system's environmental requirement as systems losses plus an ecological requirement and treats the ecological requirement as a senior "right". However, Basson (1999) cautions that: "[f]low conditions...have been fundamentally altered by ... the interbasin transfer of water, and ... it would neither be possible, nor particularly desirable, to return to the natural conditions".

For workhorse rivers (class D) such as the Orange, Great Fish and Sundays Rivers the environmental reserve calls for a volume and pattern of flows which ensures a healthy aquatic environment. Acceptable water quality in the Fish-Sundays system is defined in terms of target levels of total dissolved solids at various points downstream. These levels are 800ppm in the Great Fish River at Middleton, 600ppm achieved during artificial flood conditions for biannual diversion at Hermanuskraal, and 600ppm at Darlington Dam (Crafford, 1999).

The 600ppm standard for Darlington Dam is derived from a maximum tolerable chloride level for citrus trees of about 200-250ppm (Viljoen et al, undated; Department of Water Affairs and Forestry, 1993). Chloride typically contributes one third of total dissolved solids in the Sundays River, hence the TDS standard of 600ppm. According to Crafford, the systems manager, the latter two objectives can be achieved without special releases, but a continuous flow of 2 m^3/second is necessary to ensure 800ppm at Middleton. The resulting ecological requirement for the Fish-Sundays scheme is 63 million m^3/year.

Table 3.4 reports average monthly TDS levels for the summer of 1997/98 for tunnel outlet, selected tributaries and Middleton. Salinity of tributary flows is in the order of 1 000 to 2 000ppm. Water quality deteriorates from 150ppm at the tunnel outlet to levels of over 1 200ppm at Middleton. The average TDS level at Korhaansdrift on the Sundays River, just downstream of the point of diversion to the Sundays River scheme and Port Elizabeth, was 743ppm for 1997/98. Port Elizabeth Municipality supplied data showing average total dissolved solids of 520ppm in 1997 and 581ppm in 1998. The overall relationships in table 3.4 indicate that management more or less meets the aim of controlling salinity in the Lower Sundays.

Table 3.4: TDS levels at selected points of the Fish-Sundays system

	Teebus Q1H014	Gr. Fish Q2H002	Pauls Q3H004	Tarka Q4H013	Middleton Q7H005	Sundays N4H001
	TDS in parts per million					
Oct 97	140	558	1109	2,153	1,260	718
Nov 97	141	922	1199	2,204	1,177	
Dec 97	148	947	1240	2,088	1,368	855
Jan 98	151	639	758	2,194	1,266	
Feb 98	145	481	1196	2,119	1,284	756
March 98	122	873	1308	1,517	896	720
April 98	127	977	1173	2,126	1,267	723
May 98	126	958	1281	2,109	678	731
June 98		986		2,283	1,663	728
July 98	124	968	1253	2,236	1,246	710
Aug 98	134	958	1353	2,218	1,299	732
Sept 98	142	968	1239	2,258	1,236	759
Average	136	853	1,192	2,125	1,220	743

Source: Hydrology Database, DWAF

In arid environments where rainfall does not achieve significant leaching, any water that seeps into groundwater accumulates salts on the way down, creating the typical saline base-flows observed in the Fish-Sundays scheme (Thordiffe, undated). Basson (1999) states that it is impossible to separate the transfer scheme's role of augmenting water supplies from its diluting function. The transfer itself guarantees a stable aquatic environment and hence the environmental reserve, so that no further provision should be made for a reserve.

Alternatively one can use the desktop reserve estimate according to the Hughes model to measure ecological requirements. For class D rivers, such as the Great Fish and Sundays Rivers, 10 percent of MAR, namely 69.2 million m^3/year, is set aside to maintain ecological functions. According to the planning balance in appendix 3.1 the reserve of 69.2 million m^3/year translates into a yield reduction of 8.6 million m^3/year for the two basins combined. Kemper (1998) outlines a management plan to ensure healthy rivers and estuaries that calls for certain minimum flows and a particular pattern of flow variability in the Fish and Sundays Rivers. However, the report does not calculate an ecological reserve other than the water quality requirement at Middleton.

Kemper's reserve specification is similar to that of Venter and Van Veelen (1996) for the Orange River. It reflects the expertise collected in a number of ecological studies conducted in the region. Most of the studies support Basson (1999) that post-transfer ecology is markedly different from what was found in the rivers before the transfer scheme, and what is found in undisturbed neighbouring rivers (O'Keeffe and De Moor, 1988; O'Keeffe and Palmer, undated; Palmer and O'Keeffe, 1992; Davies et al, 1994). For example, O'Keeffe and De Moor (1987) found that only one third of pre-transfer invertebrate taxa was still present post-transfer, and that blackfly (Simulium chutteri) populations are taking on pest proportions post-transfer. Davies et al (1994) report similar impacts and that five new fish species were introduced through the tunnel.

Specific aspects of improvements listed by Kemper (1998) and Basson (1999) are to enhance habitat diversity, to reduce the dominance of blackfly, to protect and favour indigenous species, and in some case to improve water quality. Kemper's reserve specification also incorporates Palmer' 1997 recommendation of a dry period in July to reduce blackfly.

It is not clear from Basson (1999) or Kemper (1998) if the fresh water dominated status of estuaries is a result of the high base flows of the transfer scheme, or a property of the rivers in their undisturbed condition. Nonetheless, in their present condition the estuaries are part of a small group of 18 percent of South African estuaries that are permanently open (Kemper, 1998). The high base flows bring fresh water into the sea that is rich in organic matter and nutrients. The nutrients stimulate phytoplankton production, which attracts commercially important angling fish. Kemper (1998) treats the fishing as an important present use category, and calls for present estuary flows to be maintained in his reserve specification.

3.4.2.2. Irrigation requirement

Els (1965) and Badenhorst (1970) - amongst others - provide detailed descriptions of irrigation potential in the area. Estimates range between 20 000 and 70 000ha for the Fish River, and between 10 000 and 20 000ha for the Sundays River. Tyefu's potential is estimated at around 3 000ha. However, given Basson's 1999 assumption that irrigation requirements will remain constant at 1994 levels until 2030, irrigation potential is irrelevant, with the current allocation to irrigation effectively becoming the upper limit for irrigation.

Table 3.5 lists scheduled area by minor irrigation board (ditch level) at selected dates. The list is not complete. It only provides data on minor boards incorporated under the Great Fish and Sundays Irrigation Boards, but the pattern across ditches is a good reflection of development for the scheme as a whole.1993 provides a pre-transfer snapshot and 1999 shows the present situation. In 1999 nearly 48 000ha were scheduled, which is about double the 1973 figure. There was some expansion between 1973 and 1982, but much additional development took place since 1982. Almost 5 000ha was added as the Bo-Grasrug and Teebus minor irrigation boards, and the Sundays River area expanded by about 3 000ha in this period.

Table 3.5: Scheduled area by minor irrigation board at selected dates

	Scheduled area (ha)		
Irrigation board	**1999**	**1982**	**1973**
Bo-Grasrug	3753		
Teebus	1189		
Brakrivier	944	812	728
Knutsford	3285	1596	697
Baroda	1698	1318	949
Marlow	1867	1253	924
Scanlen	1872	1289	953
Tarka	1773	1185	964
Mortimer	1463	1140	777
Renfield	1549	781	642
HoughamAbrahmson	2996	2700	2532
Middleton	2149	1831	1176
Klipfontein	2396	1194	734
Boschberg	655		
Sundays River	12 213	9378	9378

Source: Irrigation board records

Irrigation requirements can be based on historical diversions or scheduled area, with the latter providing an upper limit for irrigation needs, while actual diversions offer a more accurate estimate given present crops and irrigation technology. The drawback of using actual diversions is that it varies considerably from year to year in response to climate. However, actual abstractions provide an indication of the extent to which rights are exercised.

Table 3.6 shows that between 74 and 88 percent of the potential quota was diverted in the period 1993 to 1998, suggesting that the resource is fully used in the Fish-Sundays scheme. It is known that farmers keep some margin for risk management purposes. Note, however, the contrast between the Fish River minor irrigation boards, where actual abstractions vary between 53 and 72 percent of potential abstraction.

According to table 3.6 total allocation (to use Basson's 1999 definition) to irrigation is 454 million m^3/year, compared to Stassen et al's 1997 estimate of 560 million m^3/year. The 20 percent difference in estimates is due to the fact that the Great Fish and Sundays Irrigation Boards do not control all irrigation on the Fish-Sundays scheme.

Table 3.6: Potential and actual irrigation abstraction on the Fish-Sundays scheme

Irrigation board	Quota 1999	Actual abstractions 1997/98	1996/97	1995/96	1994/95	1993/94
	million m^3/year					
Teebus-BoGrasrug	66.71	68.78	54.51	57.22	67.52	50.88
Knutsford	44.35	42.53	37.34	40.66	44.76	40.10
Baroda	22.92	20.01	16.94	19.35	22.71	19.52
Scanlen-Tarka	49.21	55.98	45.22	49.78	51.35	43.70
Mortimer	22.18	23.38	17.86	20.22	19.32	18.54
Renfield	19.36	19.65	18.84	18.60	21.34	18.44
Hougham-Abr.	37.45	30.22	21.26	25.60	28.42	24.78
Middleton	26.86	29.04	26.56	29.09	28.70	26.80
Klipfontein	29.95	19.28	16.10	16.79	19.39	18.83
Boschberg	8.19	6.86	4.33	5.57	6.21	5.39
Sundays	127.15	90.78	66.99	84.85	80.76	73.02
Total	454.33	399.20	320.57	360.91	384.00	334.14

Source: DWAF, Uitkeer (25% and 10% distribution allowance subtracted)

Basson (1999) makes a distinction between allocation and requirement, defining allocation as the volume associated with scheduled area. In terms of section 58(2) of Act 54 of 1956 a quota is an annual allocation per hectare that reflects existing water use patterns, both in terms of crop and technology (Republic of South Africa, 1958). The

National Water Act (Act 36 of 1998) replaced quotas with licences, maintaining in most cases the same allocation as the quota (Republic of South Africa, 1998). Volume quotas in table 6.3 reflect per hectare quotas of 13 500 m^3/ha/year for the Upper and Middle Fish, 12 500 m^3/ha/year for the Lower Fish and Tyefu and 9 000 m^3/ha/year for the Sundays River area.

Basson's allocation is the same as the 1956 quota and his requirement merely adjusts this quota for current crops and irrigation technology. Basson (1999) simulates, using CROPWAT, a requirement of 15 100 m^3/ha. In contrast, his quota of just under 12 000 m^3/ha for the Fish-Sundays scheme is approximately the weighted average of the area quotas. The implication is that particularly in the Great Fish basin the current crop mix requires more water than was originally planned for, and that no significant savings arise from using more efficient irrigation technology. This is precisely the opposite of the national trend where the typical irrigation system is becoming increasingly water saving (Uys et al, 1998).

Finally, it is not clear how the 2030 irrigation projection is obtained. The 570 million m^3/year budgeted for irrigation in 1994 in table 3.2 approximately equals 48 000ha at a weighted quota of 12 000 m^3/ha. This area is slightly larger than the 46 455ha reported by Dyke and Murray (1997) on which Basson (1999) based his estimate. Basson (1999) does not say how he calculates his 2030 projection of 627 million m^3/year. The 2030 estimate represents a 13 percent rise in the 1994 values. Given his emphasis on the difference between allocation and requirement one may suspect that 645 million m^3/year provides for 48 000ha at 15 100 m^3/year, but that would imply a requirement of 725 million m^3/year.

No explicit provision is made for a salinity drainage requirement since water quality is guaranteed by the scheme's management and due to a lack of data.

3.4.2.3. Municipal requirement

Two recent estimates of municipal requirement from the Fish-Sundays scheme are available in the literature. Table 3.2 lists Basson's 1999 estimate of 16 million m^3/year and table 3.7 offers Dyke and Murray's 1997 historical figure of 25 million m^3/year. The planning balance in appendix 3.1 agrees with Basson (1999). These estimates place the share of municipal water at 2 to 4 percent of annual requirement.

The planning balance shows that mining does not claim water. There is, however, a limited industrial component to Port Elizabeth's demand. The only other large city supplied by the scheme is Grahamstown, which has very little industrial development.

For Grahamstown the Fish-Sundays scheme contributes more than three-quarters of the town's water, while the small rural towns of Cradock and Cookhouse derive their entire supply from the system. While not reflected in Dyke and Murray (1997), the rural towns of Kirkwood, Addo and Enon are also completely dependent on the Fish-Sundays scheme and have an additional historical water use of 1.9 million m^3/year. In contrast the Fish-Sundays scheme accounts for less than one fifth of the Nelson Mandela Metropolitan Municipality's present demand.

Table 3.7: Historical municipal water use from the Fish-Sundays scheme

Urban centre	Historical use (million m^3/year)
Cradock	4 – 6
Cookhouse	0.36 – 0.42
Grahamstown	7.30
Nelson Mandela Metropolitan Municipality (Port Elizabeth)	11.4
Total municipal use	25.12

Source: Dyke and Murray (1997)

McKay (2000) assesses Port Elizabeth's present requirement to be 63 million m^3/year and Silva McGillvray (2000) estimates the firm yield of Port Elizabeth's integrated supply system to be 87.5 million m^3/year, at a 99 percent assurance level. The next supply source to be developed will be phase II of the Nooitgedagt treatment works that is linked to the Fish-Sundays scheme. In 2010 the city plans to construct a new reservoir in Tsitsikamma, and further phases of Nooitgedagt will only be considered after 2015 if necessary.

Silva McGillvray (2000) expects demand management strategies, as outlined in the Department of Water Affairs and Forestry's 1999 framework for conservation, to arrest the growth in water demand at the 1997 levels. It is expected that municipal demand will not increase despite projected population growth of between 2.1 and 2.8 percent per year and historical growth rates in water demand of between 2.4 and 2.7 percent per year. The Silva McGillvray projection accounts for the familiar effects of climate, population growth, expendable income and general economic growth on water demand. Per capita income is not expected to rise, but total industrial demand, should phase I of Coega be constructed, could increase industrial demand by 24.2 million m^3/year over the next five years. In contrast Basson (1999) projects that Port Elizabeth's 2030 demand from the Fish-Sundays scheme ranges between 30 million m^3/year and 135 million m^3/year and he assumes a municipal water requirement of 66 million m^3/year for the Fish-Sundays scheme by 2030.

3.4.2.4. Human reserve and associated stock watering

The National Water Act (Act 36 of 1998) gives basic human needs precedence over any other diverted use and article 9 of the Water Services Act (Act 108 of 1997) defines the reserve as "a minimum quantity of potable water of 25 litres per person per day ..." (Republic of South Africa, 1998; Republic of South Africa, 1997).

The planning balance for the entire Fish and Sundays basins allows for a human reserve of 9.5 million m^3/year, based on the 25 litre daily allocation and a rural population of just over 117 000. It is possible that the rural population accounted for in the planning balance includes the small rural towns of Cradock and Cookhouse. As indicated in table 3.2, Basson (1999) does not provide explicitly for a human reserve, but includes it as part of municipal requirement.

The Sundays River Irrigation Board points out that in the experience of this institution one of the main reasons for growth in rural water consumption is better infrastructure. As soon as a rural community is supplied with piped water, consumption increases rapidly. This suggests that while only the 25 litre allocation is legally guaranteed, we may be underestimating future demand from rural communities.

3.4.2.5. Systems losses and returnflows

In Stassen et al's 1997 hydrological analysis irrigation returnflows exactly offset systems losses. Irrigation returnflows are assumed to be 35 percent of water applied, or 199.5 million m^3/year at 1994 irrigation levels. Stassen et al (1997) estimate total systems losses, including a 15 percent distribution loss for the Sundays network, to be 132 million m^3/year. The difference is equal to the ecological requirement described in section 3.4.2.1. Systems losses, ecological requirement and returnsflows are therefore not included in table 3.2. Stassen's estimate of returnflows is low for a region where flood irrigation dominates. This observation confirms the need for further detailed investigation about actual quantities of water applied and returnflows.

However, the planning balance agrees that systems losses and returnflows approximately offset each other. Total returnflows are estimated at 118 million m^3/year, while systems losses are given as 112 million m^3/year.

3.4.2.6. Other possible consumptive requirements

The planning balance in appendix 3.1 lists zero requirements for mining, dryland sugar cane and hydroelectric power generation, and indicates small reductions in systems yield due to forestry and alien vegetation. Other non-consumptive uses of the river such as recreation and non-consumptive power generation in small private projects apply, but are not important in terms of a water balance. The most important of these is the annual canoe marathon, which coincides with the annual flushing of the rivers. Neither river is navigable. While the Great Fish River basin contains just over 7 600ha forest that reduces the yield of the system, none is found within the scheme.

3.4.3. Implications for demand management

Chapter 3 highlighted various instances of disagreement about sector-specific requirement. However, all estimates agree that water will not be a binding constraint in the next 30 years, mostly because municipal demand is not expected to rise dramatically. It also seems fairly certain that no further irrigation will be developed on the Fish-Sundays scheme and that the human and ecological reserves will not reduce firm yield significantly.

Basson (1999) reports that South Africa's current requirements from the greater Orange River system is 2 299 million m^3/year leaving about 10 percent of yield unclaimed. The most important claimant to the remaining 244 million m^3/year is Gauteng province (Vaal basin). Gauteng is expected to need 1 735 million m^3/year by 2030, and Basson (1999) proposes the construction of an additional large dam in the Orange River system to meet this requirement. His proposal leaves the Fish-Sundays transfer unaffected and even growing slightly to accommodate increasing municipal demand. It limits irrigation to present levels, thereby defining opportunity cost of irrigation in the Fish-Sundays scheme as the value of alternative irrigation in the area.

The entire discussion in Chapter 3 up to this point is in terms of requirements, rather than water demand. Basson (1999) therefore treats his estimates as upper limits to demand and calls for incorporating demand management strategies, such as those listed in Department of Water Affairs and Forestry (1999), as a condition for obtaining new licences. As explained in Chapter 2 demand management could also imply a water price increase which would cause consumers to reduce their quantity demanded, releasing water for other, presumably higher value, users.

Finally, the most important potential source of "additional" water is irrigators who hold unexercised rights to water. An unexercised water right has no value other than being a perceived insurance against climate risk, and when the water price goes up theory suggests that a sleeper right, which carries the lowest reserve price, will be sold first. A sleeper right is defined as an unused water right; a right that may or may not be scheduled and that is not developed. Not all unexercised rights are scheduled, but available data on sleeper rights are restricted to scheduled land. The percentage sleepers is calculated as follows:

$$\% \text{ sleepers} = 1 - (\text{area irrigated} \div \text{area scheduled}) \times 100$$

Table 3.8 reports the presence of sleepers in the Fish-Sundays scheme calculated from the farmer surveys discussed in Chapter 5. Generally area irrigated corresponds closely to area scheduled, indicating that most farmers irrigate all, and only, the land to which they have registered water rights. Fish River irrigators keep some rights in reserve, while irrigators in the Sundays River manage on average to irrigate a larger area than their quota suggests.

Table 3.8: Share of scheduled rights exercised in the Fish Sundays by farm type

Farm type	Average % of scheduled area irrigated
Irrigators & dairy – Great Fish	96
Stockmen – Great Fish	107
Farm businesses – Great Fish	82
Small mixed farms – Sundays	97
Large stable citrus farms – Sundays	110
Small expanding citrus farms – Sundays	108
Large expanding citrus farms – Sundays	106

Source: Calculated from farmer surveys

With the possible exception of farm businesses, table 3.8 suggests that sleeper rights are not as important in the Fish-Sundays scheme as those observed by Armitage et al (1999) along the Lower Orange River. The implication is that farm-level water constraints are approximately binding and that one should observe positive marginal water values across all farm types.

CHAPTER 4: MUNICIPAL WATER VALUE

4.1. Introduction

Chapter 4 examines municipal use, which claims a small but important share of the Fish-Sundays transfer scheme. The Department of Water Affairs historically supplied municipal water at a higher level of assurance than irrigation water. For example, during the planning of the Fish-Sundays transfer scheme provision was made for 100 percent assurance on municipal use, while irrigation supply was only guaranteed up to 70 percent of the full quota (Secretary of Water Affairs, 1971).

The National Water Act (Act 36 of 1998) formalises the arrangement by prioritising basic human needs over any other diverted use. The regulations implementing article 9 of the Water Services Act (Act 108 of 1997) defines a basic water service as, amongst others, "a minimum quantity of potable water of 25 litre per person per day or 6 kiloliter per household per month". Article 10 of the same act specifies that this basic human requirement be made available at the lowest possible price, including a zero tariff. The present study takes the argument one step further by treating the entire urban requirement as a priority use, and modelling it as a constraint to the system.

At 7.1 percent of total volume it is feasible to reserve the full urban requirement when examining the effect of tightening water constraints on marginal water values. The purpose of this chapter is to demonstrate that price elasticity of municipal demand is low and that marginal water values are noticeably higher than corresponding irrigation figures. Following Michelsen and Young (1993), it will then be argued that the value differential effectively ensures a 100 percent assurance of municipal requirement even under severe drought conditions.

A short data series restricts the scope of econometric modelling that is feasible in this case. Section 4.2 explains the data difficulties encountered and section 4.3 presents the panel data model that to some extent addresses the problem. Section 4.4 compares the estimated price elasticity to South African and international benchmarks and the chapter closes with policy implications.

4.2. Data constraints

Demand in the Nelson Mandela Metropolitan Municipality (formerly the City of Port Elizabeth) is used as a proxy for municipal demand in the basin. In Chapter 3 it was stated that the city obtains its water from a variety of sources, but since all water is pooled in a single municipal distribution system, the city's demand also applies to water from the transfer scheme.

The simplest version of the standard time-series demand model reviewed in chapter 2 was used due to data constraints. User-specific estimates of price elasticity of demand, similar to those reported by Schneider and Whitlatch (1991), have the advantage of permitting more precise policy intervention, but such models are data intensive.

The City of Port Elizabeth kept records of annual water consumption by four categories, namely residential, commercial, industrial and "outside". It recorded residential consumption separately for the city and three outlying black townships, KwaDwesi-Kwamagxaki, Ibhayi and Kwanobuhle. KwaDwesi-Kwamaxaki is the only township that has been fully metered for the duration of the sample period. Since the demand model uses positive water prices as an explanatory variable, residential areas where flat rates apply had to be excluded from the data set. However metered consumption in the city and KwaDwesi-Kwamagxaki were used as proxies of high-income and low-income patterns respectively. The categories "commercial use" and "industrial use" are taken as identified by the municipality.

Consumption data is in million m^3/year for the period 1988 to 1997. The city also provided nominal price data in cents/litre for the same period. Nominal prices were deflated using the South African Reserve Bank's consumer price index with 1995 as the base year. A sample size of 10 years is very small to estimate a multivariate demand function and household data was not readily available from the city engineer's office.

The first line of defence was to keep the model as simple as possible by lumping all other typical variables into a trend. The trend captures – amongst others – weather, income and technology changes. Since quantity demanded is estimated for the city as a whole, the trend also includes net population growth. With the possible exception of AIDS, which may in any case reduce population, no important changes are anticipated so it is not necessary to model population growth explicitly.

The data in appendix 4.1 was used to estimate four different OLS models using Eviews software. Natural logarithms were used to allow for non-linear demand curves. A double log specification allows price coefficients to be interpreted as price elasticities of demand. The models produced non-significant price coefficients, which have the right sign except for industry price. Veck and Bill (undated) report similar difficulties in their study of the Alberton-Thokoza area, where eight observations were available to explain the variation caused by five independent variables. Their solution was to interview households about their present consumption levels and introduce price variation through a simulated response to an arbitrary higher price. The estimating procedure is not reported in much detail but given the policy importance of price elasticities of water demand, contingent valuation methods are very relevant in South Africa, and deserves further investigation. However, a different approach explained below was taken in the present study.

4.3. Panel data model and results

Household, commercial and industrial consumption were pooled in an attempt to improve poor fit resulting from the very small data set. The OLS model in table 4.1 allows for different intercepts, price coefficients, and price variables for the four user groups. The category "high income residential" provides the basis for comparison.

Table 4.1: OLS model of pooled municipal water demand

	Coefficient	T-statistic	Prob.
Dependent Variable	ln Quantity		
Constant High Income Res.	6.22	4.31	0.000
Constant Commercial	4.37	3.02	0.005
Constant Industrial	-1.38	-0.96	0.345
Constant Low Income Res.	1.07	0.74	0.466
ln(Price) High Income Res.	-0.70	-2.58	0.016
ln(Price) Commercial	-0.44	-1.62	0.116
ln(Price) Industrial	0.58	2.12	0.043
ln(Price) Low Income Res.	-0.27	-0.97	0.340
Trend High Income Res.	0.03	1.71	0.098
Trend Commerce	0.01	0.69	0.499
Trend Industrial	0.03	1.39	0.177
Trend Low Income Res.	0.05	2.64	0.013
Observations	40		
Adjusted R^2	0.97		
D.W. stat	1.71		

The only counter intuitive sign in table 4.1 is the coefficient on ln(Price) Industrial which is equal to 0.58. This coefficient suggests that more water is demanded by industry as a result of a water price increase. The unexpected result is possibly due to a growth in industrial water demand derived from a growth in the demand for final products. It is further conceivable that industrial water prices were increased in response to localised industrial development, rather than the other way around. T-statistics indicate that many variables are significant at the 90 percent confidence level. All coefficients with a T-statistic greater than one are kept in order to maximise adjusted R^2.

Table 4.2 reports F-tests used to eliminate dummy variables from the specification in table 4.1. The first F-test shows a failure to reject the null hypothesis (prob.=0.58) implying that the same trend affects all user groups equally. The second test rejects the null hypothesis (prob.= 0.01) that the coefficients on natural logarithm of price are equal across all users. A further F-test fails to reject the null hypothesis (prob.=0.55) that the coefficient on the natural logarithm of price are equal for high-income residential, low-income residential and commercial users. Failure to reject implies that the same price elasticity of demand applies to these three user groups. The second test checks whether the constants are the same or not. The final F-statistic in table 4.2 rejects the null hypothesis (prob. = 0.00) that high-income residential, low-income residential and commercial demand have the same intercept.

Table 4.2: F-tests to eliminate dummy variables

Hypothesis	F-statistic	Prob.
All trend coefficients are equal	0.66	0.58
All ln(price) coefficients are equal	4.42	0.01
The ln(price) coefficients of high income residential, low income residential and commercial users are equal	0.62	0.55
The intercept coefficients of high income residential, low income residential and commercial users are equal	763.23	0.000

The objective of the testing is to reduce the unrestricted model to a standard fixed effects panel data model where quantity demanded is explained as a function of four sector-specific constants, two price variables and a single trend.

The reduced model produces a good fit and statistically significant variables of the expected sign. The results in table 4.3 contain only two counterintuitive results. The intercept for industrial demand is negative at a probability of 0.298 and the industrial price coefficient is positive as before, and in this case statistically different from zero at a more than 95 percent level. All other signs are as expected and the T-statistics indicate that the estimates are significantly different from zero at the 95 percent level at least. The Durbin-Watson statistic indicates the absence of autocorrelation.

A possible explanation for the unusual industrial price elasticity has been offered, and the only matter that remains unsolved is whether or not to include the industrial constant as part of the set of explanatory variables. Since the T-statistic is just over one, the variable is maintained in order to maximise adjusted R^2.

Table 4.3: Fixed effects model of municipal water demand

Dependent Variable – ln Quantity	Coefficient	T-statistic	Prob.
Constant High Income Res.	5.03	6.24	0.000
Constant Commercial	4.43	5.49	0.000
Constant Industrial	-1.45	-1.06	0.298
Constant Low Income Res.	2.26	2.81	0.008
ln Price HI Res./Commercial/LI Res.	-0.47	-3.10	0.004
ln Price Industrial	0.59	2.24	0.032
Trend	0.03	3.31	0.002
Observations	40		
Adjusted R^2	0.98		
D.W. stat	1.54		

Low-income households have a lower maximum willingness to pay for water than high-income households and commercial users. The coefficient on price (–0.47) indicates that the demand for municipal water in the Fish-Sundays scheme is inelastic. Finally, for reasons not adequately explained by the data available, municipal water demand in Port Elizabeth grew at an annual rate of 3 percent per year during the 1990s.

The most surprising result of the econometric model is that a poor household's demand for water is not more, or less, price elastic than the demand of a rich household. The result follows directly from the limited data set. More observations would allow the introduction of other independent explanatory variables to explore the reason why rich and poor respond in similar ways to water price increases.

The literature discussed in Chapter 2 argues that water use among low-income residential users is typically restricted to water required for drinking, cooking and basic sanitation. These categories of demand are by nature inelastic. Demand by high-income residential users is also inelastic but for a different reason. Water claims a small portion of the budget of rich households. Therefore, one would expect high-income users to be less sensitive to water price changes, leading to inelastic water demand. While the mean price elasticity of demand reported by Veck and Bill (undated) is much lower than the estimate for Port Elizabeth, they also failed to record large differences in overall price elasticity of demand between high-income and low-income groups. This matter needs further exploration.

4.4. Comparable price elasticities

Price elasticity of demand for municipal water in the Fish-Sundays transfer scheme is estimated to be –0.47, confirming the intuition that household water does not have many substitutes. Espey et al (1997) report a median short-run figure of –0.38 and median long-run estimate of –0.64 in their extensive survey of published estimates of price elasticity of demand for the United States. Dockel's 1973 estimate of –0.63 for a variety of white households, industry and commercial uses in 27 municipalities in the Witwatersrand area corresponds to Espey's et al (1997) long-run estimate, while Renwick and Archibald's (1998) more recent figure of -0.36 is consistent with a short-run estimate. The most recent South African estimate by Veck and Bill (undated) reflects an overall price elasticity of –0.17, which consists of an indoor component with price elasticity of –0.13 and a more elastic outdoor component with price elasticity of –0.38. These are short-run estimates, and are low compared to the median figure reported by Espey et al (1997). However, Veck and Bill (undated) cite eight other estimates from the literature ranging from –0.1 to –0.26.

4.5. Value of municipal water

The marginal benefit of water to consumers is R2.40 /m^3, which is equivalent to an annual rental value of R21 600 /ha for a 9 000 m^3 allocation. Bulk sales of treated water to lesser municipalities are priced at R1.26 /m^3. The city purchases water from the Department of Water Affairs and Forestry at an annual rate of R0.256 /m^3. There is no doubt that, like irrigation, municipalities capture the residual value of the resource, but the reserve price at which agriculture will start losing water to municipal use is R1.26 /m^3 minus treatment costs in 1999 terms.

4.6. Policy implications

Given scanty data, and the approach to the estimation of price elasticity, policy conclusions have to be restricted to the possibility of demand management through price. The Water Services Act (Act 108 of 1997) establishes a variety of non-price demand management strategies touched on in Chapter 2. However, none of the strategies can be commented on here except to point out that the present model confirms that the demand for municipal water in the Fish-Sundays scheme is inelastic.

The policy implication of an inelastic demand is that price alone has a limited impact on quantity demanded. In this case it is true of rich and poor alike for historical price ranges. Projections out of range tend to be inaccurate, which means that it is not possible to infer that demand by the rich will remain price inelastic if water prices are increased two-, or five-, or tenfold. Only time, or to a lesser extent contingent valuation methods, will tell.

CHAPTER 5: CONSTRUCTING AN AGRICULTURAL MODEL

2.4. Introduction

The purpose of Chapter 5 is to describe the agricultural data collection and model building process. The water demand curves that are the models' chief results are described in Chapter 6. All prices are in 1999 Rand.

Sixteen farm-level programming models will be used to estimate marginal and total water values for homogeneous irrigator groups. Regional water values are aggregated from farm level models based on the share of each farm type in the scheme.

Chapter 5 starts out with a stylised linear programming model to describe data requirements and general model attributes. Section 5.3 explains the data collection process. It discusses irrigator surveys, enterprise budgets, irrigation technologies, how risk was modelled and so on. Sections 5.4 presents the model of intensive fruit production and section 5.5 discusses the model of extensive livestock and fodder crop production.

2.5. Stylised linear programming model

Figure 5.1 presents a basic farm model. It includes crop production, livestock and crop sale activities. Fodder crops are either transferred to livestock activities or sold. Crop activities are duplicated for five irrigation systems to allow water-capital substitution. Each crop-irrigation combination has its own gross water requirement and labour need, but only one labour (management) input level was considered per irrigation-crop combination.

Labour is hired in on a monthly basis, consistent with the labour arrangement on most farms in the area. The model also incorporates price and production risk. On-farm returns to fixed factors are incorporated on a per-hectare basis for irrigated land and veld (rangeland) separately. Fixed factors are not reflected in activity budgets and include overheads, returns to land, infrastructure, and management. Overheads comprise fixed (non-variable) costs, such as administration costs, rates and taxes, commission, general maintenance and depreciation, and insurance and licences. The farm objective function maximises residual profits that are interpreted as the value of water in a Ricardian rents framework.

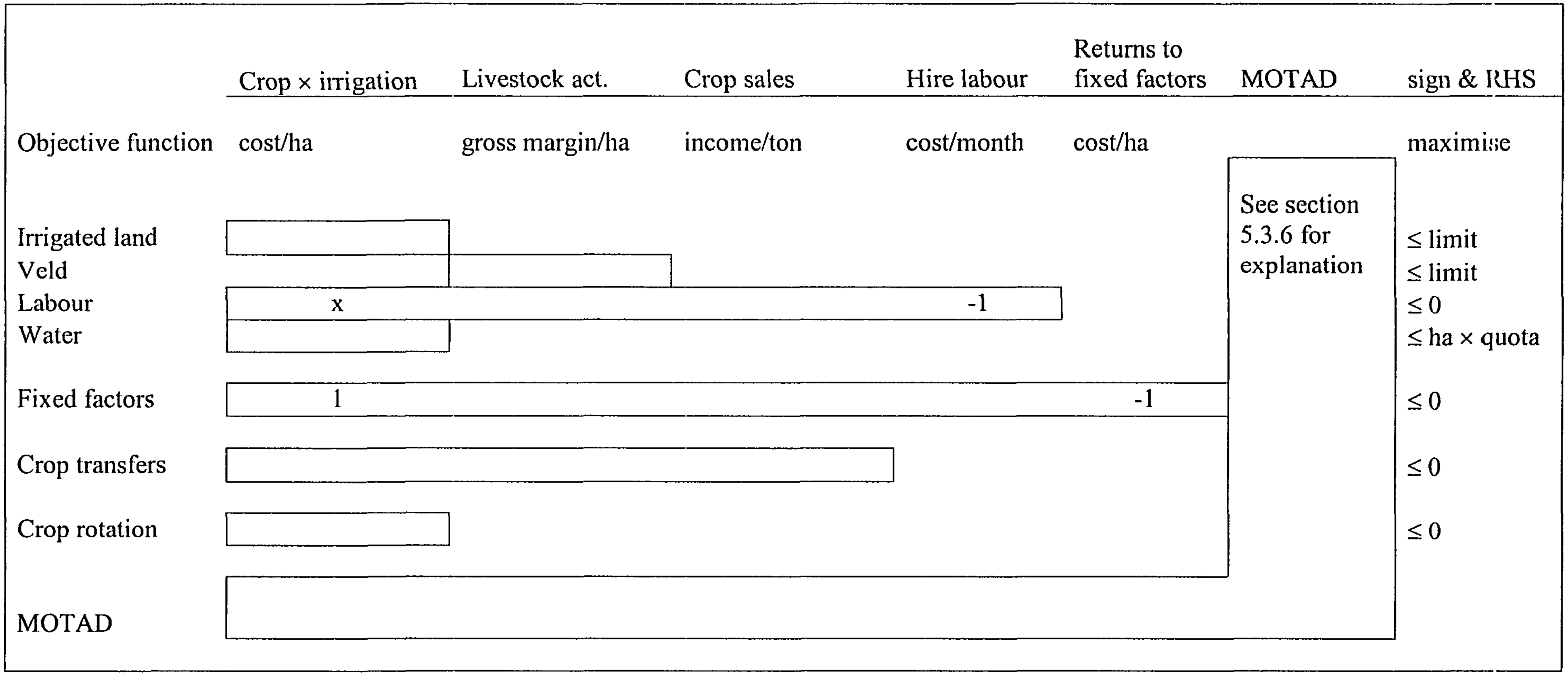


Figure 5.1: Stylised farm-level linear programming model

Overheads also include the so-called water tariff, which is levied by the Department of Water Affairs and Forestry as a flat rate per hectare and aims to recover operations and maintenance cost. A water right will sell or rent for an amount over and above the water tariff. The cost of applying water is included in the activity budget.

2.6. Data collection

Data collection took place in three stages. First, all irrigators who are registered with the two Government Water Schemes were surveyed to identify representative farms. The second step was to compile enterprise budgets in order to capture the basic production technology for a selection of crop or livestock activities identified in the irrigation survey. Existing budgets were updated with 1999 prices and confirmed in farmer interviews. In step three the basic crop technologies were adapted for five irrigation systems, on the assumption that basic crop production procedures are independent of irrigation system.

2.6.1. Irrigation survey

Farm data was collected with the aid of two postal surveys during 1999. Address lists were obtained from the Great Fish Irrigation Board in Cradock, and the Sundays River Irrigation Board in Sunlands. The two organisations represent the vast majority of irrigators in the area served by the transfer scheme. The Great Fish River Irrigation Board represents more than 30 000ha along the Great Fish River, and the Sundays River Irrigation Board represents all irrigators along the Lower Sundays River.

Both Irrigation Boards have been extended since 1999 to include a full range of stakeholders. The new organisations are known as Water User Associations.

Many farmers own multiple properties that are separately listed with the irrigation board. Where easy to identify, duplication was avoided and farmers were instructed to report on their entire operation, including farms that may be outside the service area of the transfer scheme.

Separate surveys were sent to the two groups of farmers. The surveys, included in appendix 5.1, were developed after intensive consultation with farmers and officials of the Eastern Cape Department of Agriculture. Each survey focuses on the dominant farming systems of the area at which it is targeted. 242 surveys were sent out in the Great Fish area, and 59 useable responses were received by 15 April 15 1999, resulting in a response rate of 23.8 percent. 280 surveys were posted to Sundays River on 25 July 1999 and 65 useable responses were received by 20 July 1999. The response rate by the official deadline was 17.5 percent. Nineteen additional responses were accepted after the deadline, bringing the final response rate to 24.3 percent. Data was captured in two Excel spreadsheets and is included in appendices 5.2. and 5.3.

5.3.2. Enterprise budgets

Enterprise budgets specify the production technology in terms of variable inputs and usually report gross margin. Extension services normally provide enterprise budgets, and where budgets are available, reliable, and current, the secondary source is used in programming models. The Eastern Cape Department of Agriculture produces a set of budgets, but the database does not extend to the Fish-Sundays scheme (Els, 1999).

Where available, existing budgets were updated with 1999 prices obtained from local input suppliers, specifically Cradock Saad and the Sundays River Citrus Co-operative in Kirkwood. Production coefficients, including regional differences in yield, and farm-gate prices were collected by operator recall as suggested by Beneke and Winterboer (1973). Resulting gross margins are presented in the table below and detailed budgets appear in appendix 5.4.

Table 5.1: Gross margin of crop and livestock activities in 1999 Rand for the Fish-Sundays scheme

Crops R/ha	Sundays	Upper Fish	Middle Fish	Lower Fish
Bearing citrus				
Navels	22,714			
Valencias	15,069			
Lemons	42,874			
Satsumas	9,762			
Citrus planting cost				
Replacements	(28,000)			
New developments	(36,177)			
Dry beans		2,805	3,309	3,362
Potatoes		6,594	7,829	8,759
Maize (grain)		1,966	2,279	2,279
Lucerne (year 1)		(80)	(435)	(191)
Lucerne (full production)		4,449	4,614	4,656
Rye grass		(935)	(935)	(935)
Livestock (R/LSU)	**Feedlot**	**Pasture**	**Combined**	**Veld**
Angoras		1,550	1,466	1,485
Wool sheep		1,464	1,264	989
Ostrich	8,296			
Dairy	6,464			

Source: Interviews with farmers, input suppliers and extension staff

Pre-harvest variable cost for crop activities comprises machine cost, irrigation costs, fertiliser and pest and weed control. Irrigation costs for citrus are given for drip irrigation, while flood irrigation is used for all other crops. Gross income is calculated by multiplying a farm-gate price that accounts for quality differences and marketing cost, by the typical yield for the area. Harvest cost includes machinery and transport costs, as well as picking labour. The gross margins reported in table 5.1 do not appear directly as objective function values in all cases, since fodder crop activities are separated into production and sales activities with the option of transferring hay or grain to livestock activities, and converting standing maize into silage or letting it continue to be harvested as grain. Picking labour for citrus is treated as a variable cost (at a lower wage rate) and does not enter the labour hiring activity on citrus farms.

Livestock budgets account for various categories of product and animal sales income, as well as explicit marketing costs. Variable costs include purchased feed, stock replacement expenses, veterinary services and transport. Gross margin is converted to Rand per large stock unit (LSU) for ease of comparison.

5.3.3. Isolating water values

Marginal water values can be estimated with a linear programming model if it can be shown that a shadow price is equal to marginal value product under all conditions. Beneke and Winterboer (1973) define a shadow price as the opportunity cost to the objective function of relaxing a particular constraint by one unit. In the simplest case the joint income of two (Leontiff) production processes is maximised subject to two linear resource constraints.

Consider the following production technologies:

$y_1 = y_1(x_{11}, x_{12})$ and $y_2 = y_2(x_{21}, x_{22})$

Let p_1 and p_2 be the prices of goods y_1 and y_2 and consider two linear resource constraints:

$X^1 = x_{11} + x_{21}$ and $X^2 = x_{12} + x_{22}$

Finally let λ^1 be the shadow price on resource 1, and λ^2 be the shadow price on the second input.

The firm-level problem is:

Maximise $\quad p_1 y_1 + p_2 y_2$ subject to

$$X^1 = x_{11} + x_{21}$$
$$X^2 = x_{12} + x_{22}$$

The following Lagrangian can be formulated for the problem above:

$$L = p_1 y_1 (x_{11}, x_{12}) + p_2 y_2 (x_{21}, x_{22}) + \lambda^1 (X^1 - x_{11} - x_{21}) + \lambda^2 (X^2 - x_{12} - x_{22})$$

The necessary first order conditions for profit maximisation reveal that for the first factor of production:

$$\frac{\partial L}{\partial x_{11}} = p_1 \frac{\partial y_1 (x_{11}, x_{12})}{\partial x_{11}} - \lambda^1 = 0$$

and

$$\frac{\partial L}{\partial x_{21}} = p_2 \frac{\partial y_2 (x_{21}, x_{22})}{\partial x_{21}} - \lambda^1 = 0$$

must hold simulataneously. The example illustrates that a shadow price of any factor of production is equal to the marginal value product of that input. This is true across all activities using a particular input, so that a single firm-level shadow price is calculated for each resource constraint. Furthermore, the shadow price is only positive if the resource constraint is binding. The remaining question concerns whether the shadow price is defined for a Leontiff technology, such as is typically used in linear programming models.

Shadow prices in linear programming only change between corner solutions on a convex piecewise linear production possibilities frontier, with the global maximum (best corner) depending on product price ratios (slope of the isorevenue line) and the slopes of the relevant linear resource constraints (ratio of marginal products). Silberberg and Suen (2001) point out that under these conditions the production possibilities frontier is not differentiable at a particular corner. Figure 5.2 illustrates their argument. Let DE be the isorevenue line for goods x and y, and let AG and CF represent linear resource constraints. The area OABC is the convex production possibilities set associated with the problem, and point B is the global maximum.

The production possibilities frontier is not differentiable at B, but on section AB the marginal revenue of shifting production towards good y (as measured by the slope of the isorevenue line) is greater than marginal cost (shadow price of the input described by AG). From the other direction the opposite holds for a similar reason. For segment BC the marginal cost of shifting production towards good y is greater than the marginal revenue of doing so. While there is no conventional tangency at point B, the combination of inequalities implies that marginal revenue equals marginal cost at B (Silberberg and Suen, 2001).

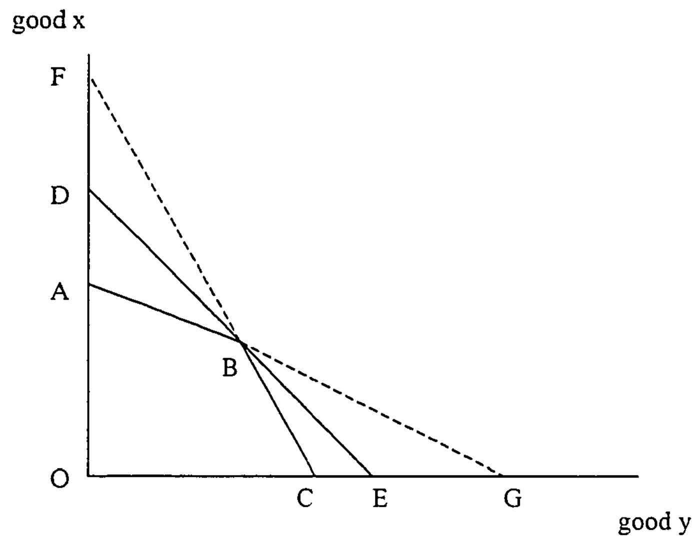


Figure 5.2: Piecewise linear quasi-convex production possibilities frontier

Total resource value is typically calculated by parametrically programming the water constraint to derive the distinctive stepped input demand function. The area under the curve is equal to the total value of water. However, the concept of Ricardian rents allows one to interpret the objective function value as a total water value if all other resources are accounted for at their going market rate. The objective function maximises a residual accruing to any pertinent constraints not modelled, as well as the fixed factors listed as resource constraints. Variable costs are already taken into account in the objective function value of each activity. Ricardo states that:

> "The produce of the earth... is divided among the three classes of the community, namely the proprietor of the land, the owner of the stock of capital necessary for its cultivation, and the labourers by whose industry it is cultivated."
> Nicholson, 1995

The concept of Ricardian rents imply that if all other input markets are competitive and present, one can solve for the equilibrium price in the missing market. One can isolate the value of water by rewarding all other fixed factors at market related rates, so that the remaining residual becomes a total water value.

5.3.4. Returns to fixed factors

In an attempt to isolate water value the farm level includes returns to all fixed factors. The fixed factors considered are land, management and farm-level infrastructure. Returns to fixed factors also include costs that cannot be readily allocated to a particular production activity. Such overheads include administration costs, rates and taxes, commission, general maintenance and depreciation, insurance and licences, as well as flat-rate water tariffs.

Table 5.2 lists the assumptions on returns to fixed factors for extensive livestock production on veld, intensive fodder and field crop production and intensive citrus production. For the Sundays River area, assumptions were compared to Ferreira and Netterville's 1996 assumptions. Returns to management is the average salary a farmer pays to himself on a per hectare basis, and payments to land and infrastructure assume a 5 percent return on investment. Land values are assumed to be R6 000/ha for irrigated land in the Fish area, and R15 000/ha for irrigated land in the Sundays area. Veld is assumed to cost R400/ha. Investment in on-farm infrastructure is assumed to be R2 000/ha in the Fish, R7 000/ha in the Sundays and R120/ha on veld. Irrigated land rents for R800 – R1000/year in the Fish River valley and for R6000/ha in the Sundays River valley.

While the model hires labour in a separate activity, a standard farm wage is also listed for ease of comparison. Labour hiring is modelled as a separate activity to facilitate a sensitivity analysis of the effects of labour costs on water use. Depreciation on machinery is usually included as a fixed cost, but as explained above, in this model it is allocated to the activity budgets as part of machine costs.

Returns to fixed factors can be introduced per activity, or as a true overhead cost for the farm as a whole. Louw and Van Schalkwyk (1997) specifies an activity that subtracts farm-level returns to fixed factors from the objective function total. Their approach implies that infrastructure is not divisible. Here the assumption is made that fixed factors, for example management, are divisible. The assumption of divisibility implies that a competent manager will make a higher wage running a larger farm than an incompetent manager will. Hence returns to fixed factors are introduced on a per hectare basis, regardless of the crop for which the particular land is selected.

Fixed costs associated with intensive livestock production are also introduced via fodder crops, but fixed cost is treated slightly differently for extensive grazing. In that case, fixed costs are expressed per hectare veld, and then subtracted from the veld-using livestock activity's objective function value.

Table 5.2: Returns to fixed factors in 1999 Rand for the Fish-Sundays scheme

Fixed factor of production	Extensive livestock	Intensive field &fodder crop	Intensive citrus
	R/ha unless specified otherwise		
Permanent labour	R700/mnth	R700/mnth	R1,000/mnth
Water tariff	-	-	461
Upper Fish	-	183	-
Middle Fish	-	202	-
Lower Fish	-	375	-
Other overheads	13.27	227	1,455
Returns to land	20	300	750
Returns to infrastructure	6	100	350
Returns to owner's management	12	951	970

Source: Interviews with local accountants, farmers and extension experts

The distinction between water costs (tariffs) and water value (residual profits) that emerges from the model specification is in itself a powerful policy conclusion. Water value (be it a rental value or a purchase price) defined as a Ricardian residual, is reduced by any cost or returns to other fixed factors. If a particular farmer has a high debt load, his resulting water value will be low. Likewise if agricultural wages increase, the resulting value of water will fall. Finally, if the Department of Water Affairs and Forestry increases water tariffs, the resulting value of water will fall, potentially to zero, if the Department extracts the entire water rent as a fee. Each of these three scenarios are relevant, and it is important to understand at this point what the implications of model specification are for the kinds of results one can expect.

5.3.5. Irrigation data

The model's irrigation component consists of three elements. The first establishes which irrigation technologies are relevant to fodder crop and to fruit producers. The second element is plant water requirement, which is a function of crop, development stage and climate. Net irrigation requirement is defined as plant water requirement adjusted for effective rainfall and leaching. In the third step net irrigation requirement is converted to gross irrigation requirement by adding distribution losses based on systems efficiency.

Data on irrigation technologies was collected in the irrigation surveys. The share of irrigation technologies, expressed as percentage of irrigated land, is reported in table 5.3. Fodder crop production uses flood irrigation while fruit production relies on micro irrigation including mirojets, drip and drip-based open ground hydroponics. In both cases the dominant technology is installed on more than 80 percent of irrigated land. Along the Great Fish River secondary irrigation technologies are movable sprinkler and centre pivot systems. A few respondents recorded the use of drip or microjet systems, but on average micro irrigation contributes less than 0.5 percent of total irrigated area. In the Sundays River valley small areas under centre pivot or flood irrigation were recorded, account for less than 20 percent of irrigated area.

Table 5.3: Share of irrigation system by farm type in 1999

Irrigation system	Fruit production	Fodder & livestock
	% of irrigated area	
Flood irrigation	6	81
Movable sprinklers	12	13
Centre pivot (sprinklers)	2	6
Micro jets	57	-
Drip/trickle	18	-
Open ground hydroponics	6	-

Source: Irrigation surveys

Table 5.4: Net irrigation requirement by crop and region

Crop	Teebus Upper Fish	Cradock Middle Fish	Klipfontein Lower Fish	Kirkwood Sundays
	m^3/year/ha			
Maize	6,760	7,030	5,310	-
Lucerne	16,500	17,390	14,900	15,600
Rye grass pastures	7,620	7,960	6,470	-
Dry beans	3,830	4,000	2,900	-
Potatoes	8,280	8,670	5,980	6,740
Citrus	-	-	-	1,157

Source: Department of Agriculture, Cradock office

The assumptions on net irrigation requirement were obtained from the Department of Agriculture's office in Cradock. Table 5.4 states net irrigation requirement by crop and region, and lists the reference stations used to calculate net irrigation requirement.

Systems efficiency assumptions were taken from industry benchmarks published by the South African Irrigation Institute in the irrigation design manual. The same source also provided a basis for cost assumptions that were confirmed with local experts. Table 5.5 also lists the cost assumptions.

Table 5.5: Selected irrigation assumptions for the Fish-Sundays scheme in 1999

	Std. flood	**Impr. flood**	**Centre pivot**	**Drag lines**	**Drip**
Systems efficiency	50%	65%	80%	70%	90%
Productive life	15	15	25	15	25
Capital cost	R300	R2,300	R9,000	R6,000	R9,000
Operating cost*	R25.80	R80	R570	R620	R1,336

* Excluding labour

Source: Dept of Agriculture, Cradock office (based on Irrigation Design Manual)

Micro irrigation is the most efficient system, but also the most expensive to operate, while flood irrigation is not an efficient distribution system, but is very cheap to install and operate. Draglines and centre pivots fit in between the two extremes in all respects. An improved flood irrigation technology is included alongside the standard flood technology, as a proxy for improvements in systems efficiency achieved through laser levelling of flood irrigated fields. While not formally researched, local experts claim an average improvement of 25 percent due to laser levelling. Anecdotal evidence suggests that up to a third of land is laser-levelled already, because farmers find the practice cost effective.

Irrigation patterns in the Fish and Sundays must be interpreted against the background of general irrigation developments in South Africa. Irrigated area has steadily increased since the 1950s, but most of the development was in micro irrigation systems. Flood irrigation has maintained about 500 000 ha for the past two decades and experts expect the trend to continue at least until 2010 (Uys et al, 1998). Thus, while increasing water scarcity may provide the incentive to convert to micro irrigation under some scenarios, flood irrigation is still feasible under others.

Moreover, the decision to convert fruit production from flood to micro irrigation may not be based on water scarcity considerations. Instead, for reasons of increasing labour cost and increasing emphasis on fruit quality it is safe to assume that citrus producers will not revert back to flood irrigation. The labour cost argument is clear, insofar as micro irrigation is laboursaving, but the fruit quality argument may be even more compelling. Micro irrigation allows the farmer much more direct control over the size and timing of water application than flood systems, and the amount of water the tree receives is used to manipulate fruit quality. Turning the fruit quality argument around also explains why experts believe that the share of flood irrigation will not be reduced in the next 20 years. In fodder crop production fruit quality is not important, and the decision amounts to a straight cost comparison unless the water constraint is binding.

The modelling implication is that fruit production will be limited to micro irrigation while fodder crops can be produced with a whole spectrum of irrigation options. Cost differences are accounted for directly, and the water constraint is tightened parametrically to model succession of technologies in the Great Fish area.

5.3.6. Modelling risk

Deterministic models overestimate the supply of high-risk crops. Some authors solve the problem by restricting high-risk crops through an exogenous constraint. The disadvantage of this approach is that residual profit also accrues to the crop mix constraint. Therefore it is more appropriate to endogenise crop mix by taking risk into account explicitly. The standard technique in a linear programming setting is MOTAD – Expected Income-Mean Absolute Income Deviation method (Hazell, 1971; Hazell and Scandizzo, 1974; Nieuwoudt et al, 1976; Teague et al, 1995).

Hazell (1971) defines risk as "uncertainties in gross margin" and identifies unknown prices, yields and costs as the main components of risk. MOTAD minimises the mean absolute value of negative deviations about the mean. Mean absolute negative deviations are defined as:

$$D = \frac{M}{2} = \frac{\sum_{r=1}^{s} \left| \min \left[\sum_{j=1}^{n} \left(c_{rj} - \overline{c_j} \right) x_j , 0 \right] \right|}{s}$$

where M is the mean absolute deviation of total farm profit and

s number of observations in sample

n number of activities on the farm

c_{rj} contribution to objective function for the j^{th} activity in the r^{th} year

$\overline{c_j}$ sample mean contribution to objective function for the j^{th} activity

x_j choice variable; the level at which the j^{th} activity is included in the solution

The linear programming problem is set up to maximise profit subject to the acceptable level of risk, which is formulated as the sum of negative deviations. This formulation is consistent with the idea that risk is a cost, but it is equally feasible to minimise risk subject to an acceptable level of income.

Hazell (1971) shows that sample mean absolute deviation is an unbiased and asymptotically normally distributed estimator of variance, but is noticeably less reliable than the traditional sample standard deviation at sample sizes of five and less. Therefore, the MOTAD technique requires at least 6 years of gross margin data for field crops for model results to reproduce the crop mixes observed in practice. For fruit, where crop mix depends on historical prices, a sample of six observations does not produce the observed cultivar mix. Deviations over 20 years were used for citrus farms.

Table 5.6: Deviations in gross income of selected crops and livestock activities

	Deviation in expected gross income in 1999 Rand/ha or Rand/livestock unit					
Crop & livestock	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Dry beans	-808	-876	206	188	220	-748
Potatoes	4,014	-2,417	-1,563	-2,481	-754	3,200
Maize grain	-326	93	-172	518	-269	1,041
Lucerne hay	80	44	-652	392	596	-460
Ostriches	250	1,603	-3,591	-432	3,968	-1,800
Wool sheep	1,465	-238	1,383	1,358	-1,476	216
Angoras	-152	-1,162	-1,026	-745	1,878	4,822
Dairy	-483	-976	1,638	536	447	-1,116

Source: Various farmer interviews

It is assumed here that variation in gross margin is due to variation in price and yield where crops are sold as cash crops. For fodder crops price variation is the only source of risk. Risk arising from variation in cost is not accounted for. Table 5.6 reports the detrended deviations in gross income used in the MOTAD model, and appendix 5.6 lists 20 years worth of citrus gross income on which citrus deviations are based.

5.4. Modelling intensive citrus production

The vast majority of farms in the Sundays River valley can be described as citrus farms, but not all farms produce citrus exclusively. The differences in crop mix, and specifically the mix of citrus varieties, characterise the different farms. In order to explain the differences, trends in citrus production are discussed first. Then the analysis of typical farms follows with a complete discussion of specific assumptions.

5.4.1. Trends in citrus production

The Sundays River valley contributes about 10 percent of South Africa's export crop. Figure 5.3 shows that citrus exports are dominated by valencia and navel oranges and that clementines and lemons are not important varieties. The category "others" consists mostly of grapefruit, but also includes a few more exotic varieties. Lemons have steadily increased from just over 3 percent of exports in 1973 to 5 percent in 1994, but are still a small component of the crop. Clementines were first exported in noticeable volumes in 1993, and contribute about the same volume as lemons nationally.

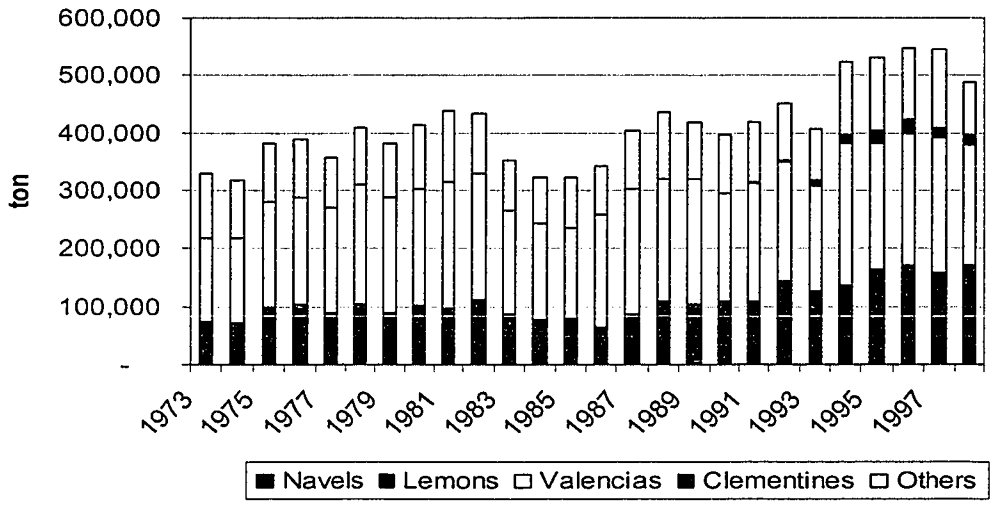


Figure 5.3: South African citrus exports by selected variety (source: Capespan)

Exports have been growing almost uninterruptedly since the mid 1980s. Exports came close to 550 000 ton in 1996, but volumes have been declining since, some claim as a result of the termination of CapeSpan's statutory monopoly.

The chief trend in figure 5.3 is the shift from valencia types to navel oranges during the 1990s. Valencias were still the most important variety, at about 220 000 ton in 1995, but its share of export volumes fell from 50 percent in 1982 to 41 percent in 1995. Navel oranges increased its share from 19.5 to 25 percent in the same period.

Long series production data to compare directly to figure 5.3 are not available for the Sundays River. Instead, figure 5.4 presents the age structure of the majority of citrus trees in the valley. The category "others" is noticeably less important than for the country as a whole and is explained by a limited grapefruit presence. The valley has a proportional share of oranges and clementines, with lemons claiming the grapefruit shortfall.

When comparing yield to data on tree age, it must be kept in mind that citrus trees take six years to mature and then have a productive life of up to 25 years. The long non-bearing stage means that yield data lags plantings between five and ten years. Since figure 5.3 represents the entire national crop, the strong local growth of 1980 to 1982 does not necessarily translate into strong export growth in the late 1980s. However, it is safe to say that the spate of plantings between 1994 and 1997 will only come into production in the next few years. Furthermore, the long productive life of trees smooth out yield trends in comparison to planting patterns. Farmers have to pick and sell the fruit of a productive tree, sometimes even at a small loss, while planting tends to respond very directly to the previous year's high prices.

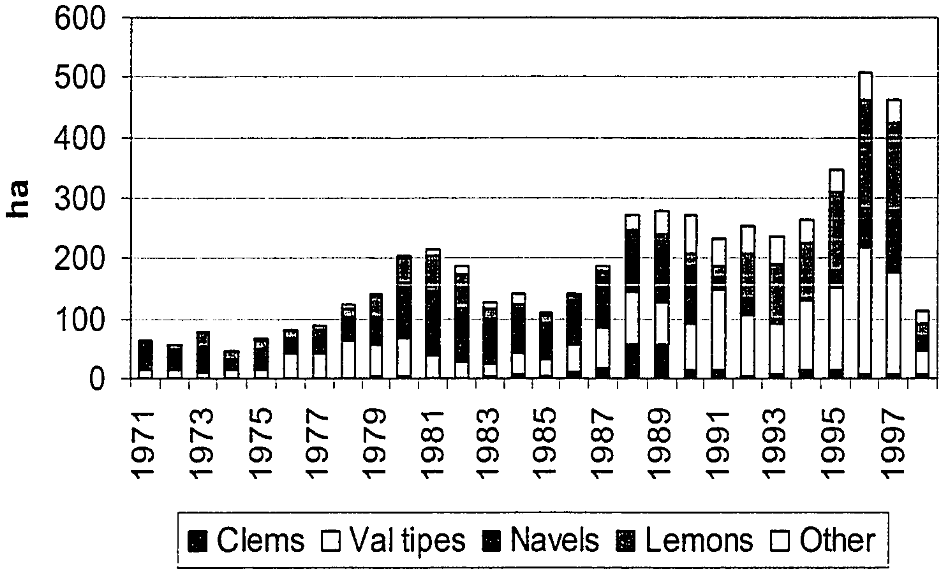


Figure 5.4: Sundays River citrus plantings by selected variety

The Sundays River plantings show noticeable orange cycles. Within oranges emphasis shifted from valencias in the late 1970s to a long period of navel expansion in the 1980s, back to valencias in the early 1990s. The plant-production lag is clear. By 1993 when export volumes were reaching record highs, navels' share of new plantings fell to the lowest level in thirty years. Furthermore, the new cycle of valencias have already been planted in the Sundays River valley, even though navel production is still steadily increasing.

The other important cycle in the Sundays River data is the lemon cycle. Lemons contributed 22 percent and 29 percent of total area during the previous planting boom in 1980 and 1981 respectively. Lemons fell to less than 2 percent of plantings from 1987 to 1989, but were back in fashion in 1993 when they contributed 39 percent of new trees planted that year. The lemon cycle implies that progressive farms will have a relatively higher investment in lemons than farms that have planted less rapidly. Less progressive farms will be more heavily committed to oranges, and will emphasise navels rather than valencias at this stage. Clementines are interesting in so far as they replaced lemons during the previous trough of the lemon cycle, but this variety has been down to less than 5 percent of plantings since 1995.

5.4.2. Specific citrus assumptions

Citrus gross margin by cultivar is listed in table 5.1, and price and quantity assumptions are given below. Details of variable cost are provided in appendix 5.4. Citrus gross margin ranges between R9 762 and R42 874 per hectare. 1999 prices were used to calculate gross income except for clementines, where the 1995 price provides a more accurate expected value.

Regarding labour assumptions, it is general practice to retain a core staff to take care of orchards during the year, and to hire in casual labour during the picking season. Permanent staff earn about R1 000/month while casual labour is hired at R180/week. Orchard maintenance requires 300 hours/ha/year, implying a rate of one permanent staff member to 7 ha orchards. Table 5.7 lists picking time by cultivar. The variation is explained by differences in yield and fruit size.

Table 5.7: Selected citrus assumptions

	Yield - ton/ha	Farm gate price - R/ton	Picking time - hours/ha
Navels	41	R794	250
Lemons	50	R1130	533
Clementines	26	R810	385
Valencias	36	R692	247

Source: Farmer interviews

The standard citrus spray program, which mainly controls thrips, scale and other minor pests, is found in Appendix 5.4. Cultivar specific issues such as black spot control, small fruit size and acid reduction are also taken into account. The budgets also allow for standard weed control, fertiliser applications and full machine costs, including depreciation.

An orchard is a productive asset similar to machinery that depreciates over time as it is used. Orchards can be depreciated in the same fashion as machinery. Alternatively, and by the assumption made here, a continuous investment to replace the existing infrastructure equally accounts for depreciation costs. New orchards are modelled as a crop rotation with bearing orchards. Young trees, in three age groups, are constrained to a certain minimum level of all orchards. See Beneke and Winterboer (1973) for the standard treatment. The linear programming model includes non-bearing orchards at exactly the replant rate specified, since young trees have a negative objective function value. The advantage of this specification is that it allows an easy sensitivity analysis of the replant rate. Budgets are listed in appendix 5.5 and linear programming tableaux in appendix 5.7.

5.4.3. Typical citrus farms

Typical citrus farms are not determined by resource access, or even crop mix, but by the rate at which new orchards are developed, or existing trees are replaced. There are three possibilities:

1. maintain investment in citrus
2. extend investment in citrus
3. consume investment in citrus

Scenario 1 describes a stable, fully developed, productive citrus unit. Scenario 2 emphasises expansion, but is not specific about how developments are financed. Scenario 3 stresses the failure to invest, but does not indicate what portion of orchards remain to be consumed. Clearly, the presence of cash crops can either be explained as a vehicle for investment or as a replacement for citrus that is being phased out, and therefore, enterprise mix has to be interpreted in conjunction with rate of expansion.

Expansion rate is calculated from farm level data on how many new trees were planted per year between 1997 and 2000. On the assumption of a 25-year orchard lifetime, 4 percent of total citrus area is subtracted per year from the new plantings for replacements of existing orchards. More than that is considered to be expansion of citrus. Farmers replace or develop whole orchards at a time and planting is often financed by the previous year's prices. Averaging plantings across the four years allows for the lumpiness in investment on a specific farm as well as the year to year variation in plantings for the valley as a whole.

Farm data was first sorted by expansion rate, which separated farms developing their citrus area from farms that have not maintained orchards in the period 1997 to 2000. Each primary group was further divided into two size groups. The four resulting farm classes and their expansion rates are given in table 5.8. Average contribution of citrus to gross income is also reported. The average farm in group A is a small mixed farm with a limited citrus component. Group B consists of large stable farms that grow citrus exclusively and group C is made up of small expanding citrus farms that use cash crops to develop orchards. The average farm in group D is a large expanding citrus operation which finances new development from existing orchards.

5.4.3.1. Small mixed farms

At an average farm size of 28.7ha, group A contains the smallest farms in Sundays River area. Group A is called small mixed farms, since they are the only farms where citrus is not the dominant crop. It contributes only 49 percent of gross income and claims 47 percent of total irrigated area. Other sources of farm income reported are lucerne hay sales (19%), dairy (10%) and market vegetables, like tomatoes, cabbages, and potatoes (10%). The citrus expansion rate, calculated over 50 percent of irrigated area, indicates that citrus is replaced regularly, but that orchards are not growing as a share of irrigated area. The standard citrus variety mix applies. Given the stable nature of the citrus enterprise, and the small farm size, the mix of enterprises may be an attempt to spread risk, which in turn suggests that the risk coefficient should be high.

Activities modelled include citrus, lucerne, potatoes (as an example of vegetables) and dairy. The potato, lucerne and dairy activities are taken from the Lower Fish. It is assumed that dairy farmers produce lucerne and rye grass, but purchase maize. Lucerne is assumed to be replaced every 5 years, so that the rotation constraint requires 20 percent of total lucerne area to be newly established.

Table 5.8: Typical citrus farms in the Sundays area in 1999

Type	Avg. farm size ha	Citrus growth* rate/year	Cultivar mix (% of gross income)			
			Navels	Lemons	Clem.	Valencia
A	28.7	-1%**	19%	13%	4%	16%
B	112.5	-2%	31%	18%	7%	29%
C	50.3	8%	21%	26%	9%	24%
D	195	4%	32%	21%	14%	28%

*Allowing for a 25 year orchard life
** Calculated on citrus area only

Source: Irrigation survey

Orchards are not modelled to be expanding. Thus the replacement constraint requires 4 percent of total citrus plantings to be in each of year 1, year 2 and year 3 for a 25-year cycle. New orchards replace existing trees, so that no additional infrastructure needs to be developed. The direct cost of planting an orchard is assumed to be R23 309 and maintenance in year 1 costs a further R4 691/ha. The maintenance cost of non-bearing citrus trees is R6 584 and R7 929/ha for years 2 and 3 respectively.

Lucerne, rye grass and potatoes are modelled using the range of irrigation technologies found in the Great Fish River area, except for centre pivots, which are not justified on such small farms. As discussed in the section on fixed cost, labour and other fixed factors are hired in on a per hectare basis. MOTAD accounts for risk, using 20 years worth of citrus data and 6 observations each for the other enterprises. The water constraint is 0.258 million m^3/year and fixed cost is modelled to be R5 691/ha.

5.4.3.2. Large stable citrus farms

Average farm size for Group B is 112.5ha irrigated land and farmers derive 89 percent of their income from citrus. Orchards are replaced, but not fast enough to maintain the investment in orchards. Citrus area shrinks at a rate of 2 percent per year, allowing for a 25-year orchard life. The observed mix of varieties is consistent with the reported slower replant rate. For example, table 5.8 shows that navels are more important than valencias, indicating that group B farms are lagging the orange cycle. Additionally, the share of lemons is low compared to the average. Given the strong recent growth in lemons, a small share of lemons indicates that these farms are not keeping up with replacements. The slow replant rate is consistent with a risk averse attitude, as is the small presence of the relatively untried clementines on large stable farms.

Production activities are restricted to the four citrus varieties. Replacement is modelled at 2 percent/year and orchard development is assumed to be replacement rather than expansion. Otherwise the standard citrus assumptions in table 5.7 and appendix 5.5 apply. Labour is modelled as before and farmers are assumed to be risk averse. The water constraint is 1.012 million m^3/year and fixed cost is modelled to be R5 691/ha.

5.4.3.3. Small expanding citrus farms

The defining property of a group C farm is that its investment in citrus is rapid and recent. The average annual growth, expressed as a percent of 1999 plantings, of citrus was 8 percent /year from 1997 to 2000. The average small expanding citrus farm derives 83 percent of gross income from citrus and has a mean farm size of 50.3ha.

The rapid investment reported by group C farmers cannot be sustained for long periods. When expansion ends, the class C farm may be 100ha, which places it in category B, or else if it enters a new phase of development when trees come into production, then it will fall in category D.

The cultivar mix on group C farms reflects recent prices more strongly than any other category. Lemons dominate the farm system at an unprecedented 26 percent of gross income. Taking into account the lemon cycles demonstrated in figure 5.4, deriving such a high share of income from lemons indicates that group C farmers are much less risk averse than any other group. On the other hand, lemons have the advantages of maturing relatively early, being conveniently spread through the season, so that they require the smallest capital investment of all citrus to pick and pack, and receiving very good prices since 1995.

Group C farms are modelled to expand citrus plantings at a rate of 8 percent per year. It is assumed that new orchards represent actual expansion. The expansion is modelled as a higher first year orchard cost. The additional cost is due to additional infrastructure requirements such as clearing land, building a dam, installing water distribution networks and so on. Infield irrigation systems and the number of trees per hectare are assumed to be identical for both new orchards. Appendix 5.5 provides the details of the expansion budget. Furthermore, while citrus contributes 83 percent of income, potatoes are included alongside the four citrus varieties to explore the effect of cash crops on citrus expansion. Vegetables are introduced for two reasons. Firstly, 45 percent of respondents in this group reported some other enterprise except citrus, and secondly, of other income sources vegetables contributed the largest average share of gross income. The water constraint is 0.453 million m^3/year and fixed cost is modelled to be R5 691/ha.

5.4.3.4. Large expanding citrus farms

A group D farm consists of 195ha irrigated land and grows at a rate of 4 percent/year of 1999 plantings. This farm derives 95 percent of gross income from citrus and reports an average cultivar mix of 32 percent navels, 21 percent lemons, 14 percent clementines and 28 percent valencias.

The replant rate is consistent with the observed crop mix. The co-operative's current valencia-navel split is 30 percent of tonnage derived from valencias and 40 percent from navels. Group D farms lead the Sundays River orange cycle in that about the same share of income is derived from navels and valencias. High-risk varieties, like clementines and lemons, make up for the small share of navels. Lemons' share of income is about average, but group D farms derive three times the average income from clementines, indicating that group D farmers are not risk averse. Citrus is the only crop modelled for large expanding citrus farms. The standard assumptions in table 5.7 and appendix 5.5 apply. The replant rotation is exogenously specified at 4 percent per year, and new orchards are assumed to be developed on new land, implying a higher development cost. The water constraint is 1.755 million m^3/year and fixed cost is modelled to be R5 691/ha.

5.4.4. Aggregating citrus results

Table 5.9 lists the share of representative farms in the irrigation survey, based on a sample irrigated area of 3 985 ha, or 27 percent of the region. Aggregation factors were calculated by applying the share of a representative farm in the sample to the entire irrigated area in the Sundays River valley.

Table 5.9: Sundays River aggregation factors

Type	% of sample*	Area sampled	Total area
		ha	
A: Small mixed	22%	890	3,209
B: Large stable citrus	25%	1,013	3,647
C: Small expanding citrus	28%	1,107	4,084
D: Large expanding citrus	24%	975	3,501
Total irrigated area: Sundays			14,587

* Values do not sum to 100% due to rounding

Source: Irrigation survey

The share of the four representative farms range between 22 and 28 percent of irrigated area. The largest group is small expanding citrus farms of which the representative farm will be aggregated to correspond to just over 4 000ha, followed by large stable and large expanding citrus farms, which each represent roughly 3 500ha. Small mixed farms are the minority, at 22 percent of the sample or 3 200ha.

5.5. Modelling extensive livestock and fodder production

The standard farming system beyond the Fish-Sundays scheme is an extensive smallstock operation. Irrigation permits fodder production, which modifies, but does not completely change, the farming system. The value of water in the Fish River area is much higher than the direct profits of fodder crops. It increases when fodder is fed to livestock, especially where livestock is supported by a combination of veld and fodder crops. In order to obtain a realistic model, crop-livestock links are specified in detail.

5.5.1. Identifying typical farms

Fish River farms were first classified into veld or irrigation, based on grazing area. Both farm types have about 80ha irrigated land, but veld farms command almost eight times as much grazing as irrigation farms. The classification is based on a valuation of veld and irrigated land at standard prices of R6 000/ha for irrigation, and R400/ha for veld. Two land values were calculated for each respondent and the farm classified in the category with the higher investment. If a farm's veld was worth more than its irrigation land, it was classified as veld, and vice versa. A preliminary analysis of enterprise mix revealed marked differences between the two types. The differences were further explored to finalise farm types. Veld farms emphasise livestock whilst irrigation farms focus on lucerne sales. Several irrigation farmers reported dairy. Vegetables and unusual crops, for example horseradish, contribute a few percent of gross income in a number of cases, but there is no clear pattern of association with veld or irrigation farms. Among vegetables, potatoes and onions are most often reported. Some farmers also mentioned ostrich-keeping and beef cattle.

The classification in table 5.10 was derived by separating dairy (group E) from the other irrigators in group F, and by dividing veld farms into large farm businesses and smaller stock farms. Most dairy operations derived more than 80 percent of gross income from dairy, and were therefore clearly identifiable. The non-dairy irrigation farms are group F. Large farm business – defined as more than 4 000 ha veld and at least 100 ha irrigated land – were put in a class by themselves. Clearly not all farms exactly meet these criteria. Where judgement calls were necessary, the classification was based on veld. For example, a farm consisting of 12 000 ha veld and 100 ha irrigation would be classified as a farm business, while 250 ha irrigation and 2 000 ha veld is considered an irrigation farm. Any remaining veld farms are included as group G stock farms.

Table 5.10: Typical farms in the Great Fish River basin in 1999

Type	Avg. farm size veld ha	Avg. farm size irrigation ha	Contribution to gross income of selected enterprises (% of income)			
			Small stock	Maize	Lucerne	Dairy
E	340	106	2%	1%	6%	85%
F	355	109	19%	10%	43%	-
G	2633	104	56%	5%	20%	2%
H	9397	218	49%	4%	15%	4%

Source: Irrigation survey

Dairy farmers (group E) control the same land as the irrigators (group F). Stockmen, (group G) also farm a similar irrigated area as irrigation farmers, but have access to significantly more veld than irrigation or dairy farms. On average farm businesses produce roughly double the irrigated land and veld to which stock farmers have access.

5.5.2. Regional difference in farm size

As explained in Chapter 3, previous studies assume a climate difference between the Upper, Middle and Lower Fish, which implies significantly different farm sizes for the regions. The argument is that a shorter growing season in the Upper Fish leads to a lower yield, which ceteris paribus implies that the minimum sustainable unit is larger in the Upper Fish than in the Lower Fish. This section examines the farm size hypothesis, before presenting assumptions on representative farms.

The Fish irrigation survey asked for the minor irrigation board in order to capture region. This question was poorly answered, with 33 of 78 respondents declining to provide information on minor irrigation board, possibly because they felt that the information would not preserve anonymity.

Data was sorted into the three regions, namely Upper Fish (Teebus, Bo-Grasrug), Middle Fish (Knutsford, Baroda, Marlow, Mortimer,Tarka), Lower Fish (Klipfontein, Renfield, Hougham Abrahamson, Boschberg, Middleton) and Unclassified. T-tests on average farm size were then compared to reject the hypothesis that average farm sizes are the same for any pair of locations. Veld and irrigated areas are kept separate. Table 5.11 reports the standard two-sampled T-statistics, as discussed in Underhill and Bradfield (1994).

Assuming that farm size has the same variance across sub-regions, the following pooled variance can be calculated:

$$s^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

The corresponding T-statistic, distributed with $n_1 + n_2 - 2$ degrees of freedom, is:

$$t_{n_1+n_2-2} = \frac{\overline{x_1} - \overline{x_2} - (\mu_1 - \mu_2)}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where

$\mu_1 = \mu_2 = 0$,	population means
x_1, x_2	sample means
s_1^2, s_2^2	sample variance
s^2	pooled variance
n_1, n_2	number of observations

The statistics fail to reject the null hypothesis at a 5 percent confidence level in all cases. Specifically, the first three sections of table 5.11 show that there is no statistical difference between average farm sizes for the four groups identified across the three areas. The data used in the first three tests only include observations for which location was identified. Separate T-statistics are calculated for irrigated land and veld. For example, the size of irrigated land on stock farms may be the same for the Upper, Middle and Lower Fish, but it does not mean the size of irrigated land on stock farms is the same as the area irrigated on dairy farms. The rest of the table shows that farm size for no farm group in any sub-region is statistically different from the farm size of the corresponding farm type that has not been classified by sub-region.

It must be pointed out that this result is dubious in specific cases. The hypothesis that the size of veld on irrigation farms in the Upper and Lower Fish are the same is not rejected at the 5 percent confidence level, but it is rejected at the 10 percent level (critical t = 2.35). Similarly, the hypothesis that the size of irrigated land on stock farms in the Middle Fish and on stock farms that were not classified by region, is the same is not rejected at the 5 percent confidence level. Again, it is rejected at 10 percent (critical t = 1.77).

The difference in veld size on irrigation farms in the Upper and Lower Fish is not important, because irrigation is the focus of modelling this type of farm. Potentially losing information about the veld component is therefore not critical to the general results. As far as the comparison of stock farms is concerned, the Middle Fish-Unspecified result will be ignored in favour of the stock farm comparison in other regions. As a conclusion observations from all regions are pooled to calculate the average farm size reported in table 5.10 and the model assumes that each farm has access to the same land.

5.5.3. Specific crop and livestock assumptions

The most important challenge in modelling the Great Fish valley is to accurately portray the complex relationship between fodder crops and livestock production. The relative shares of maize and lucerne sales are consistently just over one in four, confirming that lucerne is rotated every four to five years with maize. Other crops claim a limited share of irrigated land, and pass in and out of the rotation in response to price. Wheat is an example of a crop that recently disappeared as a result of low prices. Some farmers hope that dry beans, or even sugar beets, will eventually replace wheat as a cash crop, but beans are not reported at substantial levels in the survey yet and sugar beets are still very experimental.

Table 5.11: Differences in farm size across sub-regions of the Great Fish basin

Hypothesis	T-stat. irrigation	T-stat. veld	Degr. of freedom	Critical Tstat 5%
Avg. farm size in the Upper Fish = avg. farm size in the Middle Fish				
Dairy farms	-	-	-	-
Irrigation farms	1.17	1.17	7	2.37
Stock farms	0.50	-0.14	6	2.45
Farm businesses	0.98	-0.88	5	2.57
Avg. farm size in the Upper Fish = avg. farm size in the Lower Fish				
Dairy farms	-	-	-	-
Irrigation farms	-1.28	-3.00	3	3.18
Stock farms	-0.15	-0.15	3	3.18
Farm businesses	-1.36	0.92	3	3.18
Avg. farm size in the Middle Fish = avg. farm size in the Lower Fish				
Dairy farms	0.71	0.62	4	2.78
Irrigation farms	-1.42	-0.80	8	2.31
Stock farms	0.56	-0.36	7	2.37
Farm businesses	-0.54	0.80	4	2.78
Avg. farm size in the Upper Fish = avg. farm size region unspecified				
Dairy farms			-	-
Irrigation farms	-0.97	-1.62	8	2.31
Stock farms	1.00	-1.05	9	2.26
Farm businesses	-1.30	0.11	4	2.78
Avg. farm size in the Middle Fish = avg. farm size region unspecified				
Dairy farms	-0.22	-0.70	9	2.26
Irrigation farms	0.35	-0.29	13	2.16
Stock farms	2.10	-1.90	13	2.16
Farm businesses	-0.33	-1.10	5	2.45
Avg. farm size in the Lower Fish = avg. farm size region unspecified				
Dairy farms	-1.22	-0.95	9	2.26
Irrigation farms	1.69	0.68	9	2.26
Stock farms	1.58	-1.22	10	2.23
Farm businesses	0.24	-1.39	3	3.18

The complex relationship between stock and the dominant fodder crops makes it impossible for most farmers to report accurately on the amount of lucerne and maize fed to animals. However, the standard practice seems to be that inferior quality hay and maize are fed to stock. This distinction was not picked up in the model. Instead, a quality adjusted average price was calculated for feed crops and the model was left to select sales or feeding. On the livestock side systems relying exclusively on fodder have to be compared to systems that use veld or a combination of veld and fodder crops. Finally maize and lucerne hay can be fed to sheep, angora goats, dairy cows or ostriches with equal ease.

The field crops modelled are lucerne, maize, dry beans, potatoes and rye grass. Yield and price assumptions are presented in table 5.12. Two lucerne activities capture the difference between plant year performance and full production. Takeoff is slower in the Upper and Middle Fish than in the Lower Fish due to a shorter growing season.

Table 5.12: Selected assumptions on crop yield and grazing capacity

Description	Upper Fish	Middle ton/ha	Lower	Price R/ton
Lucerne (full production)	14.1	15	15	440
Lucerne (plant year)	9.9	10.5	10.5	440
Maize	7.44	8	8	600
Rye grass	17.67	19	19	-
Potatoes	22.3	24	25	930
Dry beans	1.86	2	2.1	3,400
		ha/LSU		
Grazing capacity	17	16	15	

Source: Interviews with farmers and extension specialists

The set of representative farms for the Great Fish River valley are constructed from the basic farm systems in table 5.10, the farm size assumptions, and the yield assumptions. Assumptions on yield and grazing capacity are listed in table 5.12. Consultation with farmers and other experts revealed that yield differs very little across regions. Length of growing season does have an effect, but often management factors override climate effects. Except for potatoes and beans, yields are assumed to be the same in the Middle and Lower Fish.

Rainfall introduces an additional complication with regard to lucerne hay production, since it determines the quality of hay harvested in a particular season. Yield is higher in the Lower Fish due to higher rainfall, but in the average season a smaller quantity of class 1 hay is harvested than in the Upper Fish. The highest lucerne income is achieved in the Middle Fish.

The lucerne price is a weighted average adjusting for quality differences. The average quality was calculated from weekly rainfall from October to May at Grass Ridge Dam (Upper Fish), Halesowen Experimental Farm (Middle Fish) and De Mistkraal Dam (Lower Fish). Lucerne is harvested at a rate of about one cut per month. Where there are at least two dry weeks in a month, it is assumed that that month's crop is first grade. If it rained in more than two weeks during the month but less than 50mm in a given week, it is assumed that the farmer harvested second grade hay. If more than 50mm were recorded in a particular week and it rained in more than two weeks during the month, it is assumed that the hay would still be harvested, but be of inferior quality.

The specific composition of crops on irrigated land is the result of incorporating risk, and is only determined by the assumption about a particular farmer's coefficient of risk aversion. However, with lucerne, the split between new lucerne and full bearing fields is an exogenous constraint based on the agronomic reality of how long a field lasts. Once established, a lucerne field remains productive for four to six years, depending, amongst others, on cultivar, irrigation practices and whether the field is grazed or not. If planted in late summer, a field can produce two-thirds of a full crop the following summer, in its first season. Establishing a lucerne field is relatively expensive compared to later maintenance, and the first year's hay crop barely covers the initial expense. In the subsequent growing seasons the crop reaches full production, which then tapers off towards the end of productive life. The lucerne lifecycle is modelled as a two-stage process, consisting of an establishment year and a full bearing period of 4 years. A standard crop rotation constraint is used to ensure replacement on a five-year cycle. Apart from lucerne, rye (for dairy) and maize that are the key fodder crops, dry beans and potatoes are also modelled. Potatoes are a high value cash crop, while dry beans are an example of a more extensive lower value field. Again, crop rotation is not a model constraint.

The model uses standard feed transfer assumptions, which explicitly transfers a ton of lucerne hay, rye grass or maize for the respective crop activities to a variety of livestock activities. Selling activities for lucerne hay and maize allow the option of cash fodder sales alongside livestock activities. There are no fodder buying activities, because all fodder used for livestock is assumed to be farm produced.

While it is common practice to run small stock on old lucerne fields, the lucerne livestock link in the model was simplified by assuming that all hay is cut, baled and taken out of the field to be fed to stock under feedlot conditions. As such the assumption used in the model is a conservative estimate of what it really costs to transfer farm produced lucerne to own livestock.

Six wool sheep and angora systems model the variety of small stock options reported in the farm survey. Of the two, wool sheep is a less risky option, because of the mutton component, which to some extent buffers the wool price. Angoras are risky, and present in much smaller numbers. Furthermore, the specific type of grazing on a particular farm as well as the farmer's personal preferences will determine which stock is kept, but wool sheep provide a good standard of comparison, and angora goats are an example of extensive high risk options. Each of the small stock systems are duplicated into three discreet feed options. Again, the feed options approximate a continuum, starting with exclusive use of veld and ending with feedlot conditions. Most commonly though, farmers use a combination of extensive grazing and intensive pasturing for small stock. Ostriches and dairy are also included as examples of feedlot operations.

Details of budgets are attached as appendix 5.5 and linear programming tableaux are included as appendix 5.7.

5.5.4. Typical fodder and livestock farms

The general assumptions discussed in the previous sections apply to the typical farms identified in section 5.5.1. The same four farm types – irrigation, stock, farm business and dairy – are included in the Upper Fish, Middle Fish and Lower Fish models.

5.5.4.1. Dairy farms

Dairymen derive 85 percent of their gross income from milk and surplus animal sales, and their most important secondary source of income is lucerne hay sales. Less important enterprises include small stock (3 percent) and maize (1 percent). In a highly untypical system one dairy farmer receives 30 percent of his income from vegetables sales, but nobody else reports vegetables.

The activities modelled are dairy, lucerne, maize and rye grass. Sales of lucerne and maize are permitted, but rye grass is not sold. Dairy production is restricted to the fodder level that can be produced given the farms land and water resources. Dairy cows are not modelled on veld. All irrigation technologies are modelled.

Dairy farming is assumed to be a relatively high-risk operation. Six years of price variation are included for dairy, lucerne prices and maize prices. Yield is assumed to be constant for the period.

5.5.4.2. Irrigation farms

Group F receives its income mainly from lucerne hay sales (43 percent), small stock production (19 percent) and maize (10 percent). The crop system rotates lucerne and maize, with a small contribution from other crops, like potatoes (3 percent) and dry beans (2 percent of gross income). Ostrich raising is present, but not an important enterprise (4 percent). Other crops are present at very low levels.

The model will include lucerne, small stock, maize, dry beans and potatoes, which make up 77 percent of average gross income in this group. The stock activities are wool sheep and angoras, produced according to each of the three systems. Even though the irrigation farm has very little access to veld, the model can pick to run a few sheep or goats on the natural grazing. The standard lucerne replacement rotation applies, and farmers are modelled to be moderately risk averse

5.5.4.3. Stock farms

The stockmen in group G are a homogeneous group who manage a system of wool sheep (41 percent) and angora goats (13 percent) supported by fodder crop production. Group G farmers emphasise small stock to a greater extent than any of the other groups. The contribution of lucerne (20 percent) and maize (5 percent) indicate that irrigated land on the average stock farm is planted to the same rotation described in the previous section. Large areas of veld support higher stock numbers. Other minor enterprises reported, are beef cattle (8 percent), dairy (2 percent), potatoes (1 percent) and ostriches (3 percent).

Compared to irrigation farms, more importance should be placed on extensive livestock than on crop sales. The model is constructed to select lucerne, maize, dry beans and potatoes for irrigated land. Beans and maize are assumed to be cash crops without any interaction with the livestock activities, but lucerne is modelled to be either sold or fed to livestock. The same livestock assumption applies as for irrigators. Again, model is restricted to replace lucerne at a rate of 20 percent per year, but crop mix is determined through a strategy of minimising income variation. Farmers are assumed not to be very risk averse.

5.5.4.4. Farm businesses

On average group H, the multiple owner farm businesses, are also heavily involved in wool sheep (41 percent) and angora goats (8 percent). Beef cattle (10 percent) and ostrich farming (8 percent) are more important to this group than to any other farm types. Lucerne (15 percent) and maize (4 percent) are slightly less important than before, but again the same basic crop rotation characterises this farming system. The smaller contribution of crops to gross income is due to the greater emphasis on converting feed into some livestock product. Ostrich farming is quite important in this regard. Vegetables (8 percent of gross income), and specifically potatoes, show that farm businesses are also diversified in terms of crops.

The farm business is modelled in the same way as the stock farm, but the available enterprises are extended to include potatoes and ostriches. Maize and lucerne are both linked to ostrich production, and wool sheep and goats are assumed to be able to make use of lucerne in a pasture system or in combination with extensive grazing. A third livestock activity for sheep and goats relies on veld exclusively. The rotating crop is not restricted, but risk is incorporated through a MOTAD routine Owners of farm businesses are assumed to be relatively risk averse, but not quite as risk averse as stock farmers.

5.5.5. Aggregating fodder and livestock results

According to the Great Fish River Irrigation Board total irrigated area in the Upper Fish was 11 764ha in 1999, while the Middle Fish comprised 7 829ha, and the Lower Fish consisted of 15 122 ha irrigated land. Of the three regions the Middle Fish best represented in the survey. In the Middle Fish 1 985ha (25%) irrigated land was reported on, while 1 856 ha and 1 717ha were reported on the Upper Fish and Middle Fish respectively.

Table 5.13: Fish River aggregation factors

	% of sample*	Area (ha)	Aggregation factor
Type 1: UF irrigator	47%	5,529	65
Type 2: UF stockman	38%	4,470	53
Type 3: UF farm business	11%	1,294	9
Type 4: UF dairyman	-	-	-
		11,764	
Type 1: UF irrigator	31%	2,427	29
Type 2: UF stockman	27%	2,114	25
Type 3: UF farm business	26%	2,036	15
Type 4: UF dairyman	17%	1,331	16
		7,829	
Type 1: UF irrigator	37%	5,595	66
Type 2: UF stockman	20%	3,024	36
Type 3: UF farm business	33%	4,990	36
Type 4: UF dairyman	10%	1,512	18
		15,122	

* Values do not sum to 100% due to rounding

Source: Irrigation survey

Aggregation factors were calculated by applying the share of a representative farm in the sample in a particular region to the total irrigated area. The survey of Upper Fish farms returned no dairy farms. Thus the most noticeable difference between the Upper Fish and the other two regions is the relatively high proportion of irrigators in the Upper Fish compared to the Middle and Lower Fish. The Upper Fish also has a slightly higher presence of stock farms and fewer farm businesses than the other regions.

5.6. Summary of farm models

Table 5.14 provides brief summaries of the 16 typical farms in the model. Types 1 – 4 represent the Upper Fish, types 5 – 8 represent the Middle Fish and types 9 – 12 model the Lower Fish. The four farm types identified for the Sundays River region are listed as types 13 – 16. The linear programming models for the base case for farm types 9 – 16 are included in appendix 5.7.

Table 5.14: Summary of typical farms for the Fish-Sundays scheme

Number	Category	Description
1	Upper Fish Irrigation Farm	Crops & small stock; 85ha irrigation, 265ha veld
2	Upper Fish Stock Farm	Crops & small stock; 85ha irrigation, 2 540ha veld
3	Upper Fish Farm Business	Crops, potatoes, small stock, ostriches; 140ha irrigation, 7 900ha veld
4	Upper Fish Dairy Farm	Crops & dairy cows; 85ha irrigation, 0ha veld
5	Middle Fish Irrigation Farm	Crops & small stock; 85ha irrigation, 265ha veld
6	Middle Fish Stock Farm	Crops & small stock; 85ha irrigation, 2 540ha veld
7	Middle Fish Farm Business	Crops, potatoes, small stock, ostriches; 140ha irrigation, 7 900ha veld
8	Middle Fish Dairy Farm	Crops & dairy cows; 85ha irrigation, 0ha veld
9	Lower Fish Irrigation Farm	Crops & small stock; 85ha irrigation, 265ha veld
10	Lower Fish Stock Farm	Crops & small stock; 85ha irrigation, 2 540ha veld
11	Lower Fish Farm Business	Crops, potatoes, small stock, ostriches; 140ha irrigation, 7 900ha veld
12	Lower Fish Dairy Farm	Crops & dairy cows; 85ha irrigation, 0ha veld
13	Sundays Small Mixed Farm	Citrus, dairy, fodder crops, potatoes; 29ha land
14	Large Stable Citrus	Citrus, area shrinks by 2%/year; 112ha land
15	Small Expanding Citrus	Citrus, area grows by 8%/year; 50ha land
16	Large Expanding Citrus	Citrus, area grows by 4%/year; 195ha land

CHAPTER 6: IRRIGATION WATER VALUE: COMPARING FODDER CROPS TO EXPORT FRUIT

6.1. Introduction

Chapter 6 derives farm-level irrigation demand schedules for the 16 typical farms defined in the previous chapter and reports marginal and total water value for commercial irrigation. All values are in 1999 Rand.

Section 6.2 interprets the shadow price on water as a marginal value product and explains how factor demand curves are derived. Section 6.3 presents the deterministic case, which estimates the upper bound of irrigation water values. Section 6.4 endogenises enterprise mix by accounting for risk, and section 6.5 presents risk-adjusted enterprise mixes and water values. Section 6.6 examines shifts in demand due to changes in various key assumptions including water tariffs, labour costs, yield and irrigation systems efficiency. The chapter ends with a summary of water value to commercial irrigation.

6.2. Interpreting the data

Each farm-level water demand function is constructed through parametric programming from a series of binding water constraints and matching shadow prices that form the typical stepped input demand function associated with a linear programming model.

Water demand is completely elastic on the horizontal portion of a step, implying that willingness to pay for water does not change for often a considerable quantity range. Willingness to pay only increases when a new activity becomes profitable. At that quantity the demand curve is discontinuous, and the shadow price jumps to a higher level to form the vertical portion of the step.

A smooth downward-sloping demand curve, as introduced in Chapter 2, requires a degree of factor substitutability, which is by definition impossible in a linear programming model that is constructed from a series of Leontiff technologies. However, resource substitution is approximated by duplicating a particular crop activity using different production techniques. See Cornfort and Lacewell (1982) and Teauge et al (1995) for examples of implementation.

Chapter 2 explained that profit maximisation under prefect competition requires marginal value product to be equal to factor price, and Chapter 5 showed that marginal value product is equal to the shadow price in optimum solution of a linear programming model. Therefore, if shadow price are equal across users a particular allocation if efficient, and if they are not equal, reallocation will improve total benefit.

Agricultural shadow prices in R/m^3, adjusted for further distribution cost, are commensurate with a municipal wholesale price for water. The shadow price is also converted into a per-hectare rental value to allow easy comparison to other production costs such as labour. While R/m^3 is a useful price specification to compare across uses, it is unlikely that irrigation water will be purchased in cubic meters. Chapter 2 shows that most water transactions are either the outright purchase of a right, or an annual rental of a quantity of water sufficient to irrigate one hectare or acre of land. Furthermore, in order to compare water value to the value of land, annual the annual value of water is capitalised at a real interest rate of 5 percent. The capitalised value is likewise given in R/m^3 and R/ha. For example, a shadow price of R0.01/m^3 is equal to a rental value of R90/ha/year assuming a quota of 9000 m^3/ha. The purchase price for this example, assuming a real capitalisation rate of 5 percent, is R1800/ha. Where a separate market for water does not exist, land that carries water rights, reflects the water value – be it on an annual or capitalised basis – as part of the land price.

6.3. Production under perfect certainty

The optimal enterprise mix under perfect certainty bears very little resemblance to observed farming systems. In many cases the results are of a "all or nothing" nature; the most profitable activity at one water level is simply the most profitable at all water levels, implying perfectly elastic factor demand curves. Estimates of water values are unrealistically high in the deterministic case and provide the upper bound of willingness to pay for water since the cost of bearing risk is not yet accounted for.

Introducing an exogenous constraint that limits the share of "high value" crops is a proven approach to model calibration.The standard argument to justify this kind of constraint is that it represents fixed factors not taken into account by the model. However, part of the residual accrues to the crop constraint so that total water values are overestimated in the process.

Instead the present study introduces risk as a cost of production that endogenises enterprise mix to isolate a water value. The models in appendix 5.7 show crop rotation constraints that govern horticultural relationships, for example the proportion of young trees to bearing trees or the proportion lucerne to other field crops, but no restriction is placed on the proportion of high value activities in the optimal solution. The cost of bearing risk is introduced with the MOTAD sub-model described in Chapter 5. In the deterministic case the risk aversion coefficient is set at zero, implying that no compensation is needed for taking risk.

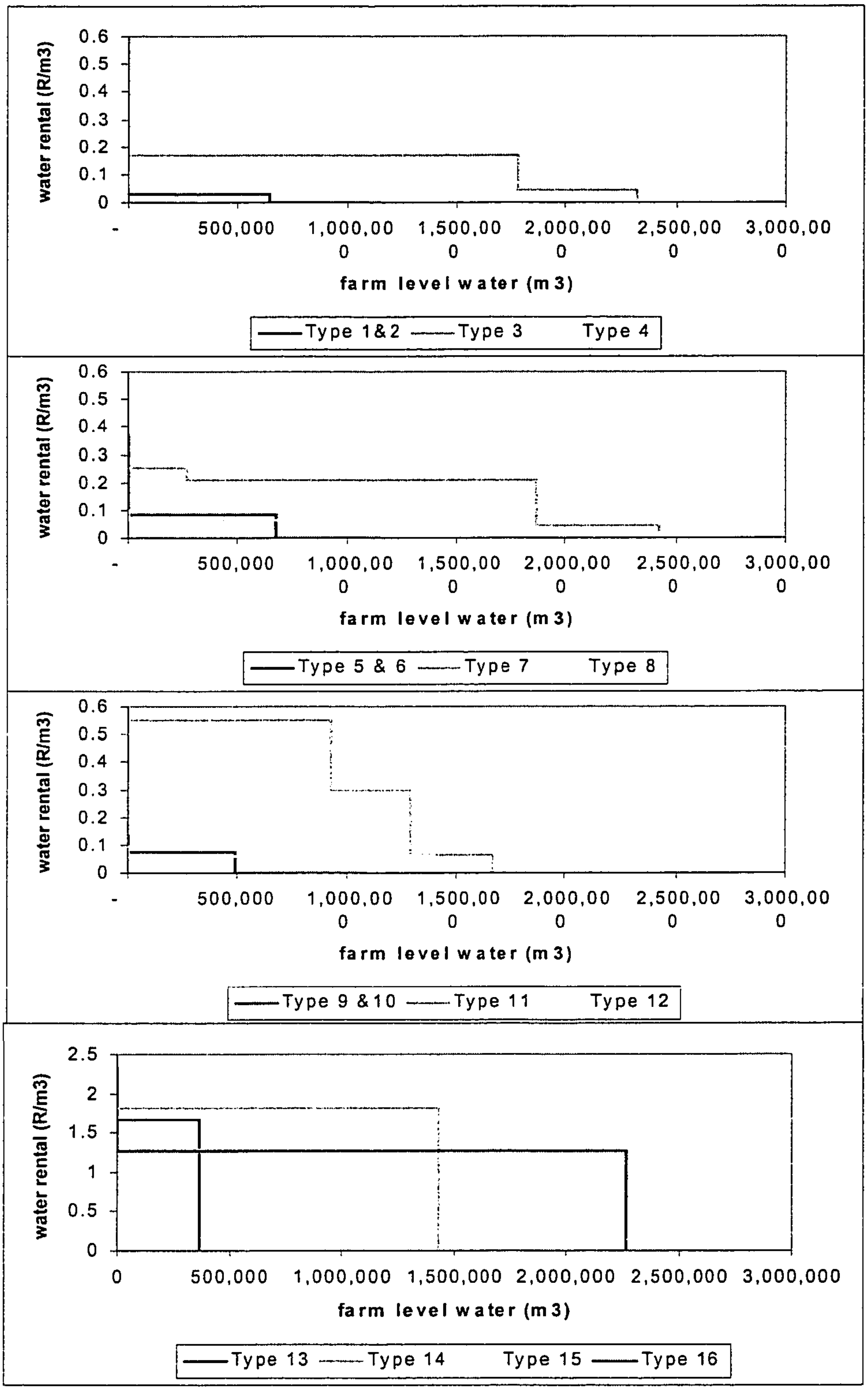


Figure 6.1: Water demand for irrigation under perfect certainty

Figure 6.1 portrays the family of farm-level water demand curves under perfect certainty and tables 6.1 to 6.4 show the price and quantity data from which the functions are constructed. Whilst not an proper base-line case, this scenario provides useful insights into the mechanics of the model.

Firstly, the water demand curves for farm types 1 and 2 coincide, and the same is true for types 5 and 6 and types 9 and 10. In each case the pair are the irrigated farm and the stock farm for a particular region. Irrigated farms and stock farms have identical irrigated areas and enterprise options. Dairy farms have the same irrigated area, but a different crop mix to choose from, and hence different water demand functions.

The second result concerns crop-livestock interactions in the Upper, Middle and Lower Fish. Under perfect certainty the most profitable crop is not a fodder crop, except for dairy where only fodder crops are modelled. The fact that farmers choose a system that is not the most profitable confirms that they are not risk neutral.

If the water constraint is set equal to zero, the model picks the most profitable livestock activity involving veld only, in this case angora goats, and calculates the optimal level of profits. The profits at zero water under perfect certainty ranges between R3 707 (Upper Fish irrigators) and R287 530 (Lower Fish farm businesses).
The profit in this scenario does not accrue to water, and is subtracted from subsequent residuals to isolate water values.

Irrigators and stock farmers in the Upper, Middle and Lower Fish choose their optimal crop mix from lucerne, maize and dry beans. Under perfect certainty beans are the most profitable crop. The dairy model replaces beans with rye pasture, and models the dairy activity as using farm-produced fodder only. The crop mix is thus determined by dairy feed requirements. The farm business models include potatoes, which is a risky and high value crop, alongside the crop activities modelled on irrigation and stock farms. Potatoes replace beans as the optimal crop for farm businesses under perfect certainty.

The vertical shifts in water demand are almost entirely explained by crop profitability. For example, in the Upper Fish the shadow prices at a water constraint of 500 000 m^3 are R0.031/m^3 for irrigators and stockmen, R0.169/m^3 for farm businesses and R0.061/m^3 for dairy farms. The five-fold increase in shadow price between irrigators and farm businesses is due to the difference in gross margin for potatoes and beans. The fodder crops for dairy generate a marginal value product of about twice the marginal value of water in bean production. In the Middle Fish the shadow price of water at 500 000m^3 is R0.084/$m^3$for irrigators and stockmen, while the shadow price for dairy farms remains more or less the same at R0.063/m^3. In the Lower Fish the shadow price of water to irrigators falls to zero at 500 000m^3, while the shadow price generated for dairy farms is at this constraint is R0.0611/m^3.

Current allocation is defined as the water quotas operating under the previous water act, namely 13 500m^3/ha for the Upper and Middle Fish, 12 500m^3/ha for the Lower Fish and 9 000m^3/ha for the Sundays River. In the Upper and Middle Fish the quota corresponds to a farm-level demand of 1 147 500m^3 for irrigators, stockmen and dairymen and a farm-level constraint of 1 890 000m^3 for farm businesses. Shadow prices for the current allocation are given in table 6.1 for farm types 1 – 4, in table 6.2 for farm types 5 – 8, in table 6.3 for farm types 9 – 12 and in table 6.4 for farm types 13 – 16.

Irrigators and stockmen in the Upper Fish (type 1 and 2) record zero shadow prices at the present allocation, since the optimal solution under perfect certainty requires less water than the quota. A non-binding water constraint suggests that farmers are willing to sell, rather than buy, water. A zero marginal value does not mean that the total value of water is zero. For type 1 and 2 the total value of water is R20 291 and the average value is R0.0177/m^3.

Table 6.1: Rental values and corresponding purchase prices for selected basis changes for the Upper Fish (types 1 – 4) under perfect certainty

Farm-level water constraint	Rental value in R/m3				Purchase price in R/ha			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
-	0.0312	0.0312	0.3436	0.1085	8,414	8,414	92,761	29,299
1			0.1699	0.0615			45,879	16,606
4,484	0.0312				8,414			
4,485	0.0312				8,414			
52,341		0.0312				8,414		
453,112		0.0312				8,414		
453,113		0.0312				8,414		
651,099	0.0312	0.0312			8,414	8,414		
651,100	-	-						
1,147,500	-	-		0.0615				16,606
1,549,445				0.0615				16,606
1,549,446				0.0403				10,893
1,634,727				0.0403				10,893
1,634,728				0.0358				9,655
1,685,849				0.0358				9,655
1,685,850				0.0235				6,338
1,783,599			0.1699				45,879	
1,783,600			0.0468				12,643	
1,890,000			0.0468				12,643	
2,014,595				0.0235				6,338
2,014,596				-				
2,318,400			0.0468				12,643	
2,318,401			-					

The present allocation in the Upper Fish is a binding constraint for farm businesses (R0.0468/m^3) and dairy farms (R0.0615/m^3). Converted to a purchase price the average farm business will pay up to R12 643 to purchase an additional 13 500m^3/ year. Dairy farmers are willing to pay up to R16 606 for the same amount of water.

The constraint level at which the marginal value of water falls to zero is the maximum amount of water a farm will use if water is priced volumetrically. As explained before, flat rates on a full quota does not enter into profit maximisation. It means that profit maximising farmers should use their entire quota given the present rate structure. However, the Department of Water Affairs and Forestry has converted, or is planning to convert, to volumetric pricing. When they do, type 1 and 2 farms (irrigators and stock farms) will reduce quantity demanded to 651 100m^3, while types 3 and 4 (farm businesses and dairymen) would be expected to expand their use beyond the current allocation. Unfortunately the proposed pricing change may possibly be mostly cosmetic since it is proposed that farmers will be charged on a volumetric basis, but still for the full licence volume, or quota.

Table 6.2: Rental values and corresponding purchase prices for selected basis changes for the Middle Fish (types 5 – 8) under perfect certainty

Farm-level water constraint	Rental value in R/m3				Purchase price in R/ha			
	Type 5	Type 6	Type 7	Type 8	Type 5	Type 6	Type 7	Type 8
-	0.0844	0.3702	1.9183	0.0972	22,798	99,958	517,944	26,253
1	0.0844	0.0844	0.2547	0.0634	22,798	22,798	68,770	17,112
40,541	0.0844				22,798			
40,542	0.0844				22,798			
269,228			0.2547				68,770	
269,229			0.2547				68,770	
679,999	0.0844	0.0844			22,798	22,798		
680,000	-	-			-	-		
1,147,500	-	-		0.0634				17,112
1,631,383				0.0634				17,112
1,631,384				0.0389				10,490
1,719,443				0.0389				10,490
1,719,444				0.0343				9,261
1,772,444				0.0343				9,261
1,772,445				0.0223				6,014
1,867,600			0.2062				55,676	
1,867,601			0.0447				12,074	
1,890,000			0.0447				12,074	
2,120,779				0.0223				6,014
2,120,780				-				-
2,427,600			0.0447				12,074	
2,427,601			-				-	

Table 6.2 reveals the same broad patterns in water values for the Middle Fish as those discussed for the Upper Fish. At a farm-level water constraint of 500 000m^3 the shadow price for irrigators and stockmen is R0.084/m^3. The shadow price at the same constraint level is R0.063/m^3 for dairy farms and R0.2062/m^3 for farm businesses. The purchase prices to relax the 500 000m^3 constraint vary between R17 112/ha for dairy and

R68 770/ha for farm business for a hectare's worth of water. As before, the difference in shadow price can be explained by crop choice, with beans selected as the optimal crop on irrigation and stock farms, and potatoes chosen by farm businesses. Dairy farms produce the same mix of maize, lucerne and rye grass as before.

Shadow prices at the present allocation also follow the same pattern as in the Upper Fish. Again, zero shadow prices are recorded for irrigation and stock farms, while the shadow prices is R0.0447/m^3 for a farm businesses and R0.0634/m^3 for dairy. Total value of water to irrigators (type 5) and stockmen (type 6) is R57 419, dairy farms (type 8) derive a total benefit of R727 26 from their present allocation of water, and the total value of water for farm businesses (type 7) is R451 449. Average water values are R0.0500/m^3 for irrigators and stockmen, R0.2389/m^3 for farm businesses and R0.0634/m^3 for dairy farms in the Middle Fish.

Table 6.3: Rental values and corresponding purchase prices for selected basis changes for the Lower Fish (types 9 – 12) under perfect certainty

Farm-level water constraint	Rental value in R/m3				Purchase price in R/ha			
	Type 9	Type 10	Type 11	Type 12	Type 9	Type 10	Type 11	Type 12
-	0.07227	0.13335	0.5495	0.0921	18,068	33,339	137,387	23,032
1		0.07227	0.5495	0.0612		18,068	137,387	15,291
70,075	0.07227				18,068			
493,000	0.07227	0.07227			18,068	18,068		
493,001	-	-						
929,600			0.2988				74,710	
990,384			0.2988				74,710	
1,062,500	-	-		0.0612				15,291
1,288,000			0.2988				74,710	
1,288,002			0.0648				16,202	
1,396,003				0.0612				15,291
1,396,004				0.0514				12,844
1,462,593				0.0514				12,844
1,462,594				0.0421				10,525
1,505,772				0.0421				10,525
1,505,773				0.0251				6,272
1,674,399			0.06481				16,202	
1,674,400			-				-	
1,750,000			-				-	
1,815,068				0.0251				6,272
1,815,069				-				-

Table 6.3 shows that water is less constraining in the Lower Fish than in the Middle Fish or Upper Fish. The 500 000m^3 farm-level constraint is no longer binding on irrigation and stock farms, but the marginal value of water to dairymen is still in the order of R0.06/m^3 at this level, producing a purchase price of R15 291/ha. Farm businesses in the

Lower Fish record a marginal water value of R0.5495/m^3 at 500 000m^3, which converts to a purchase price of R137 387 for 12 500m^3.

The current allocation poses no constraint to farm businesses in the Lower Fish. Type 11 farms will reduce their maximum quantity demanded to just under 1.674 million m^3/year if volumetric rates are introduced. The total value of water at the current quota is R643 008 for type 11 farms. Dairymen derive R98 383 from their allocation and irrigators and stockmen earn R35 630 from the current water quota. The corresponding average water values are R0.0311/m^3 for irrigators and stockmen, R0.0857/m^3 for dairymen and R0.3402/m^3 for farm businesses.

The demand for water on irrigation and stock farms is about half of the demand for water on dairy farms in the Upper Fish, but in the Middle and Lower Fish marginal water values at the current quota are much closer for all three groups. This indicates how sensitive a linear programming model is for assumptions about crop yield. Getting administered prices "exactly right" will not only require an extensive simulation effort, but detailed agronomy and climate studies as well. Furthermore, irrigators and stockmen are much less responsive to price changes than dairy farms, suggesting that one may succeed in getting prices right and still not achieve the necessary reduction in quantity demanded.

Table 6.4: Rental values and corresponding purchase prices for selected basis changes for the Sundays (types 13 – 16) under perfect certainty

Farm-level water constraint	Rental value in R/m3				Purchase price in R/ha			
	Type 13	Type 14	Type 15	Type 16	Type 13	Type 14	Type 15	Type 16
0	2.3359	1.8199	1.2727	1.7634	420,465	327,583	229,092	317,413
1	1.6668	1.8199	1.2727	1.2727	300,017	327,583	229,092	229,092
261,000	1.6668				300,017			
359,286	1.6668				300,017			
359,287	-				-			
450,000			1.2727				229,092	
579,919			1.2727				229,092	
579,920			-				-	
1,008,000		1.8199				327,583		
1,431,875		1.8199				327,583		
1,431,876		-				-		
1,755,000				1.2727				229,092
2,261,687				1.2727				229,092
2,261,688				-				-

Table 6.4 presents water demand curves for the Sundays River. Shadow prices are significantly higher for citrus farms than for fodder and livestock farms. At a constraint of 500 000m^3 water is a binding constraint on large stable, small expanding and large expanding citrus farms and purchase prices range between R229 092/ha for type 15 and

16 and R327 583/ha for type 14 farms. The result for small and large expanding citrus farms suggests that the residual awarded to water is smaller when a larger proportion of a farm is not in production.

Lemons dominate crop mix in the deterministic model and since a single irrigation technology is modelled for citrus the resulting demand curve forms a single step in all four cases. The completely unresponsive demand curve leaves no room for demand management. Even with drip irrigation, lemons require more than 9 000m^3/ha/year, suggesting a binding water constraint at the present allocation.

For the same crop mix, a larger irrigated area shifts farm level water demand to the right, increasing the area under the demand curve, or total value, in the process even if the shadow price remains the same as before. A good is example of the effect of farm size is found in the bottom panel of figure 6.1 where the difference in water value for type 15 (small expanding citrus farms) and type 16 (large expanding citrus farms) is only the result of a difference in farm size. Otherwise, the two types are identical. Consequently shadow prices are identical at R1.2727, but the total value of water is R738 084 for small expanding farms and R2 878 527 for large expanding farms.

6.4. Using risk to simulate observed enterprise mix

MOTAD captures six years of variation in gross margin for farm types 1 – 12 and 20 years of variation for Sundays River farms. MOTAD penalises the objective function by a risk premium based on the risk aversion coefficient selected; the higher the risk aversion coefficient, the larger the slice of the Ricardian pie claimed by risk, and the lower the total water value will be. This section identifies the farm-level risk aversion coefficient that best simulates observed enterprise mix.

Figure 6.2 shows the relationship between risk aversion coefficient and shadow price at the current water quota for all farm types. Except for citrus farms there is no systematic relationship between risk coefficient and shadow price. Hence the risk coefficient used in further modelling is chosen entirely for how well it simulates enterprise mix.

Table 6.5 (Upper Fish), table 6.6 (Middle Fish), table 6.7 (Lower Fish) and table 6.8 (Sundays) present the two most likely candidates for each farm type. Each table lists activities down the column at levels at which they enter into the optimal solution for the current water constraint and the risk aversion coefficient reported in the top portion of the table. The top section also lists a marginal water value (R/m^3/year and R/ha/year) and total farm-level water value generated by the optimal solution (R/farm/year). In certain cases the shadow price at the current water level is zero, for example irrigators and stockmen in the Middle Fish and irrigators in the Lower Fish, but for most farms the water constraint is binding. Risk adjusted water values are about the same size as current water tariffs.

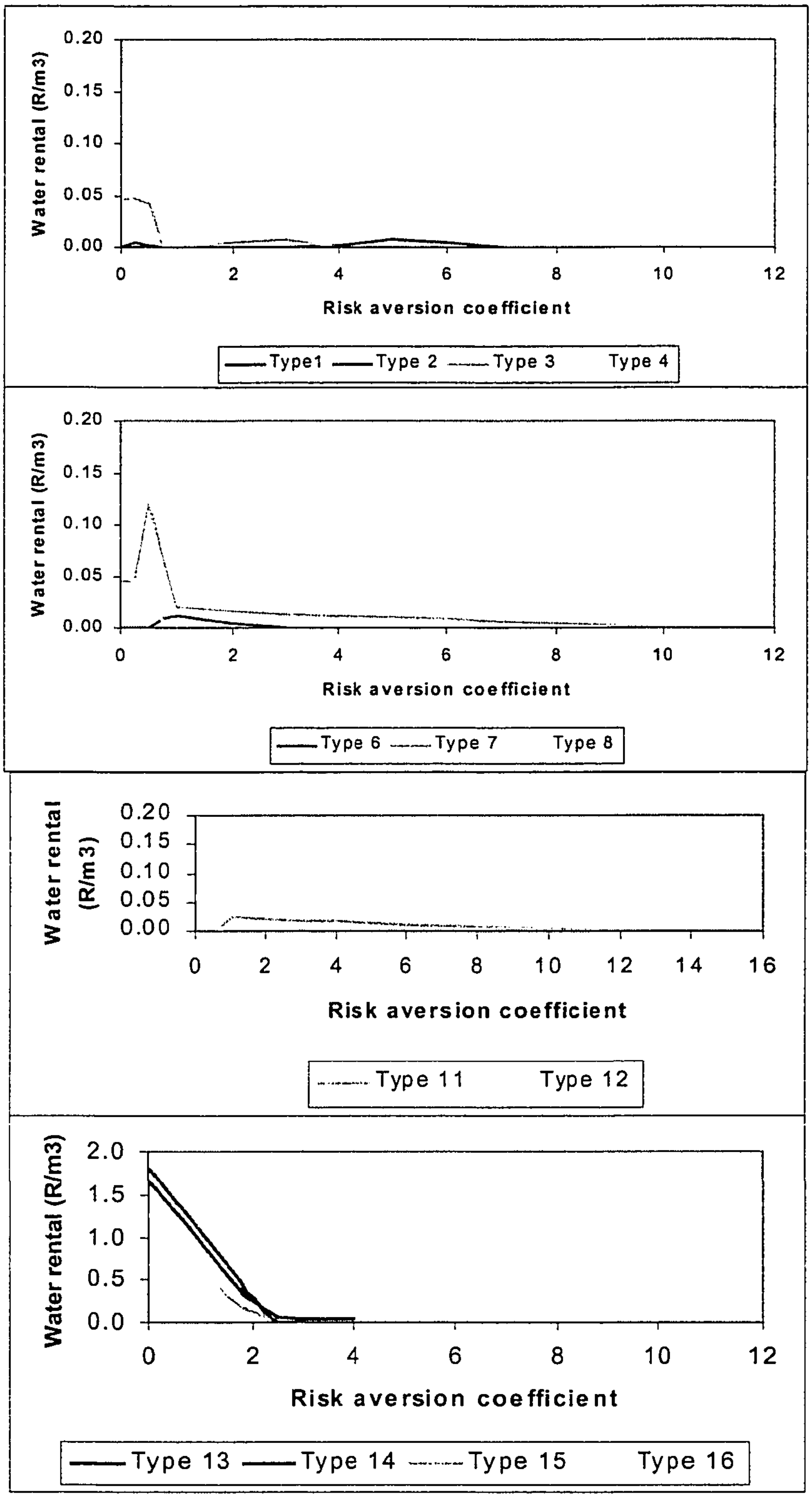


Figure 6.2: Relationship between shadow price and risk aversion coefficient at present water allocation levels for the Fish-Sundays scheme

Table 6.5: Selected enterprise mixes and associated risk aversion coefficients for the Upper Fish (types 1-4)

	Type 1		Type 2		Type 3		Type 4	
Risk aversion coeff	0.25	0.5	4.00	5.00	2.50	3.00	0.25	0.50
Shadow price (R/m3)	0.0041	0.0011	0.0015	0.0067	0.0106	0.0075	0.0412	0.0225
Shadow price (ha equiv.)	55	15	21	91	143	101	556	303
Total water value (R/farm)	8,741	5,591	14,459	9,250	21,189	14,145	47,228	25,763
Activities								
Potatoes flood std	NA	NA	NA	NA	-	-	NA	NA
Potatoes laser improved	NA	NA	NA	NA	-	-	NA	NA
Potatoes centre pivot	NA	NA	NA	NA	-	-	NA	NA
Potatoes drag lines	NA	NA	NA	NA	-	-	NA	NA
Potatoes drip	NA	NA	NA	NA	-	-	NA	NA
Dry beans flood std	17.20	5.89	2.23	-	9.71	9.71	NA	NA
Dry beans laser improved	-	-	-	-	-	-	NA	NA
Dry beans centre pivot	-	-	-	-	-	-	NA	NA
Dry beans drag line	-	-	-	-	-	-	NA	NA
Dry beans drip	-	-	-	-	-	-	NA	NA
Maize flood std	0.00	0.00	3.56	5.72	-0.00	-0.00	-	15.57
Maize laser improved	-	-	-	-	-	-	20.24	-
Maize centre pivot	-	-	-	-	-	-	-	-
Maize drag line	-	-	-	-	-	-	-	-
Maize drip	-	-	-	-	-	-	-	-
Harvest maize	0.00	-	3.56	5.72	-	-	3.43	2.64
Sell maize	-	0.00	26.49	42.58	-	-	16.82	12.93
Young lucerne flood std	6.16	6.68	6.56	6.49	11.00	11.00	-	-
Young lucerne flood impr	0.00	0.00	-	-	-	-	0.00	4.91
Young lucerne centre pivot	-	-	-	-	-	0.00	6.39	-0.00
Young lucerne drag line	-	-	-	-	0.00	-	-	0.00
Young lucerne drip	-	-	0.00	0.00	-	-	-	-
Lucerne flood std	24.62	26.72	26.24	25.94	44.02	44.02	-	-
Lucerne flood improved	-	-	-	-	0.00	0.00	-	19.66
Lucerne centre pivot	-	-	-	-	-	-	25.56	-
Lucerne drag line	-	-	-	-	-	-	0.00	-
Lucerne drip	-	-	-	-	-	-	-	-
Sell lucerne	-	-	191.87	207.23	42.17	282.08	-	-
Rye grass flood std	NA	NA	NA	NA	NA	NA	-	8.27
Rye grass flood improved	NA	NA	NA	NA	NA	NA	10.76	-
Rye grass centre pivot	NA	NA	NA	NA	NA	NA	-	-
Rye grass drag line	NA	NA	NA	NA	NA	NA	-	-
Rye grass drip	NA	NA	NA	NA	NA	NA	-	-
Ostriches	NA	NA	NA	NA	-0.00	-0.00	NA	NA
Sheep veld	-	-	-	1.24	-	-	NA	NA
Sheep combination	-	-	13.32	12.21	34.77	22.63	NA	NA
Target cells Sheep pasture	8.60	9.33	-	-	-	-	NA	NA
Angora veld	1.34	1.34	5.87	5.26	20.99	12.06	NA	NA
Angora combination	-	-	-	-	-	-	NA	NA
Angora pasture	-	-	-	-	-	-	NA	NA
Dairy cows	NA	NA	NA	NA	NA	NA	79.19	60.91
Hirelabour	53.36	42.97	50.10	48.01	114.16	90.23	57.02	47.18
OH Irrigation	47.98	39.30	38.58	38.15	64.73	64.73	62.95	48.42
OH Veld	256	256	2,540	2,540	7,900	4,882	NA	NA

Table 6.6: Selected enterprise mixes and associated risk aversion coefficients for the Middle Fish (types 5-8)

	Type 5		Type 6		Type 7		Type 8	
Risk aversion coeff	0.60	0.75	3.00	3.50	4.00	9.00	0.25	0.50
Shadow price (R/m3)	0.0003	0.0000	0.0000	0.0000	0.0120	0.0025	0.0427	0.0233
Shadow price (ha equiv.)	-	-	-	-	161	33	577	314
Total water value (R/farm)	5,215	3,960	19,347	12,539	91,054	59,217	49,016	26,684
Activities								
Potatoes flood std	NA	NA	NA	NA	-	-	NA	NA
Potatoes laser improved	NA	NA	NA	NA	-	-	NA	NA
Potatoes centre pivot	NA	NA	NA	NA	-	-	NA	NA
Potatoes drag lines	NA	NA	NA	NA	-	-	NA	NA
Potatoes drip	NA	NA	NA	NA	-	-	NA	NA
Dry beans flood std	67.54	5.32	18.45	3.41	8.38	8.38	NA	NA
Dry beans laser improved	-	-	-	-	-	-	NA	NA
Dry beans centre pivot	-	-	-	-	-	-	NA	NA
Dry beans drag line	-	-	-	-	-	-	NA	NA
Dry beans drip	-	-	-	-	-	-	NA	NA
Maize flood std	-0.00	0.42	0.00	0.00	3.12	3.12	-	17.60
Maize laser improved	-	-	-	-	-	-	19.12	-
Maize centre pivot	-	-	-	-	-	-	-	-
Maize drag line	-	-	-	-	-	-	-	-
Maize drip	-	-	-	-	-	-	-	-
Harvest maize	0.00	0.42	-	0.00	3.12	3.12	15.88	14.62
Sell maize	-	3.37	0.00	-	-	-	-	-
Young lucerne flood std	3.49	0.70	3.54	3.86	10.23	10.23	-	-
Young lucerne flood impr	-0.00	-	-	-	0.00	0.00	0.00	4.91
Young lucerne centre pivot	-	-	-	0.00	-	-	6.39	-0.00
Young lucerne drag line	-	-	-	-	-	-	-	0.00
Young lucerne drip	-	-	-	-	-	-	-	-
Lucerne flood std	13.97	2.79	14.16	15.46	40.92	40.92	0.00	0.00
Lucerne flood improved	-	-	-0.00	-	-	-	6.10	5.62
Lucerne centre pivot	-	-	-	-	-	-	-0.00	-
Lucerne drag line	-	-	-	-	-	-	-	-
Lucerne drip	-	-	-	-	-	-	-	-
Sell lucerne	-	-	51.41	46.95	-	-	-	-
Rye grass flood std	NA	NA	NA	NA	NA	NA	24.41	22.47
Rye grass flood improved	NA	NA	NA	NA	NA	NA	-	-
Rye grass centre pivot	NA	NA	NA	NA	NA	NA	-	-
Rye grass drag line	NA	NA	NA	NA	NA	NA	-	-
Rye grass drip	NA	NA	NA	NA	NA	NA	-	-
Ostriches	NA	NA	NA	NA	12.99	12.99	NA	NA
Sheep veld	-	-	-	-	11.21	11.21	NA	NA
Sheep combination	-	-	10.86	12.35	34.84	34.84	NA	NA
Target cells Sheep pasture	5.19	1.04	-	-	-	-	NA	NA
Angora veld	1.34	1.34	8.12	6.96	11.62	11.62	NA	NA
Angora combination	-	-	-	-	-	-	NA	NA
Angora pasture	-	-	-	-	-	-	NA	NA
Dairy cows	NA	NA	NA	NA	NA	NA	80.42	74.02
Hirelabour	102.43	11.93	56.69	39.79	126.35	126.35	55.33	52.78
OH Irrigation	85.00	9.23	36.16	22.73	62.65	62.65	59.79	55.03
OH Veld	256	256	2,540	2,540	7,900	7,900	NA	NA

Table 6.7: Selected enterprise mixes and associated risk aversion coefficients for the Lower Fish (types 9-12)

	Type 9		Type 10		Type 11		Type 12	
Risk aversion coeff	0.75	1.00	0.70	0.80	4.00	10.00	0.25	0.50
Shadow price (R/m3)	0.0000	0.0000	0.0014	0.0000	0.0163	0.0026	0.0378	0.0171
Shadow price (ha equiv.)	-	-	17	-	204	32	472	213
Total water value (R/farm)	2,017	1,382	71,504	68,129	125,098	56,019	40,161	18,128
Activities								
Potatoes flood std	NA	NA	NA	NA	-	-	NA	NA
Potatoes laser improved	NA	NA	NA	NA	-	-	NA	NA
Potatoes centre pivot	NA	NA	NA	NA	-	-	NA	NA
Potatoes drag lines	NA	NA	NA	NA	-	-	NA	NA
Potatoes drip	NA	NA	NA	NA	-	-	NA	NA
Dry beans flood std	4.19	1.73	28.43	22.94	9.07	9.07	NA	NA
Dry beans laser improved	-	-	-	-	-	-	NA	NA
Dry beans centre pivot	-	-	-	-	-	-	NA	NA
Dry beans drag line	-	-	-	-	-	-	NA	NA
Dry beans drip	-	-	-	-	-	-	NA	NA
Maize flood std	0.00	-	0.00	0.00	3.39	3.39	19.18	15.91
Maize laser improved	-	-	-	-	-	-	-	-
Maize centre pivot	-	-	-	-	-	-	-	-
Maize drag line	-	-	-	-	-	-	-	-
Maize drip	-	-	-	-	-	-	-	-
Harvest maize	-	0.00	0.00	-0.00	3.39	3.39	15.93	13.22
Sell maize	0.00	0.00	-	-	-	-	-	-
Young lucerne flood std	0.63	0.40	5.81	5.29	10.76	10.76	-	-
Young lucerne flood impr	-	-	-	0.00	-0.00	-	-0.00	5.08
Young lucerne centre pivot	0.00	-	-	-	-	-	6.12	-
Young lucerne drag line	-0.00	-	-	-	-	-	-	-
Young lucerne drip	-	-	-	-	-	-	-	-
Lucerne flood std	2.53	1.60	23.25	21.17	43.04	43.04	-	-
Lucerne flood improved	-	-	-	-	-	-	-	20.31
Lucerne centre pivot	-	-	-	-	-	-	24.49	0.00
Lucerne drag line	-	-	-	-	-	-	-	-
Lucerne drip	-	-	-	-	-	-	-	-
Sell lucerne	-	-	-	-	-	-	-	-
Rye grass flood std	NA	NA	NA	NA	NA	NA	-	-
Rye grass flood improved	NA	NA	NA	NA	NA	NA	-	-
Rye grass centre pivot	NA	NA	NA	NA	NA	NA	-	-
Rye grass drag line	NA	NA	NA	NA	NA	NA	-	-
Rye grass drip	NA	NA	NA	NA	NA	NA	-	-
Ostriches	NA	NA	NA	NA	14.12	14.12	NA	NA
Sheep veld	-	-	-	-	13.75	13.75	NA	NA
Sheep combination	-	-	-	-	36.47	36.47	NA	NA
Target cells Sheep pasture	0.94	0.59	8.64	7.86	-	-	NA	NA
Angora veld	1.34	1.34	17.68	17.68	12.64	12.64	NA	NA
Angora combination	-	-	-	-	-	-	NA	NA
Angora pasture	-	-	-	-	-	-	NA	NA
Dairy cows	NA	NA	NA	NA	NA	NA	80.67	66.92
Hirelabour	10.52	5.97	89.17	78.97	137.48	137.48	57.53	49.47
OH Irrigation	7.35	3.73	57.50	49.40	66.27	66.27	59.98	49.76
OH Veld	256	256	2,540	2,540	7,904	7,904	NA	NA

Table 6.8: Selected enterprise mixes and associated risk aversion coefficients for the Sundays (types 13-16)

	Type 13		Type 14		Type 15		Type 16	
Risk aversion coeff	2.00	2.25	2.40	2.50	1.00	1.50	1.75	1.80
Shadow price (R/m3)	0.2469	0.1525	0.0352	0.0063	0.5898	0.2862	0.0776	0.0435
Shadow price (ha equiv.)	2,222	1,373	317	57	5,308	2,576	699	392
Total water value (R/farm)	64,431	39,811	35,451	6,380	265,417	128,797	136,236	76,388
Activities								
Year 1 trees	0.40	0.40	1.58	1.58	3.10	1.77	12.11	12.11
Year 2 trees	0.40	0.40	1.58	1.58	3.10	1.77	12.11	12.11
Year 3 trees	0.40	0.40	1.58	1.58	3.10	1.77	12.11	12.11
Navels	-	-	0.42	5.96	-	-	-	0.29
Lemons	8.90	8.90	22.08	16.23	29.49	16.85	115.00	114.71
Clementines	-	-	18.36	17.31	-	-	-	-
Valencias	-	-	33.25	34.61	-	-	-	-
Potatoes flood std	-	-	NA	NA	-	-	NA	NA
Potatoes laser improved	14.75	14.75	NA	NA	-	20.96	NA	NA
Potatoes drag lines	-	-	NA	NA	-	-	NA	NA
Potatoes drip	-	-	NA	NA	-	-	NA	NA
Dairy cows	-	0.00	NA	NA	NA	NA	NA	NA
Rye grass flood std	-	-	NA	NA	NA	NA	NA	NA
Rye grass flood improve	0.00	0.00	NA	NA	NA	NA	NA	NA
Rye grass drag line	-	-	NA	NA	NA	NA	NA	NA
Rye grass drip	-	-	NA	NA	NA	NA	NA	NA
Young lucerne flood std	0.00	-	NA	NA	NA	NA	NA	NA
Young lucerne flood imp	-	-	NA	NA	NA	NA	NA	NA
Young lucerne drag line	0.00	0.00	NA	NA	NA	NA	NA	NA
Young lucerne drip	0.00	0.00	NA	NA	NA	NA	NA	NA
Lucerne flood std	-	-	NA	NA	NA	NA	NA	NA
Lucerne flood improved	0.00	-	NA	NA	NA	NA	NA	NA
Lucerne drag line	-	-	NA	NA	NA	NA	NA	NA
Lucerne drip	0.00	-	NA	NA	NA	NA	NA	NA
Sell lucerne	-	-	NA	NA	NA	NA	NA	NA
Hirelabour	80.74	80.74	225.22	215.44	124.36	134.80	485.02	484.59
OH Irrigation	17.49	17.49	78.84	78.84	38.80	32.65	151.31	151.31

Comparing across farm types it seems that irrigators and dairymen are more risk loving that stockmen, farm businesses operators and citrus producers. The result is reasonable since limited access to veld constrains the set of feasible enterprises for irrigators in the model, as well as in reality. Price and yield risk are therefore spread over a smaller number of activities, with fewer opportunities to cross-subsidise in a given year. Dairy farms represent the extreme case where the entire variation in farm income is determined by the variability of dairy income. To take on dairy farming without other options a farmer must therefore be less risk-averse than a farmer who can diversify into livestock and cash crop production. The citrus models only produce the observed cultivar mix at relatively high risk aversion coefficients, but as expected expanding citrus farms (type 15 and 16) are less risk-averse than the mixed citrus farm and large stable citrus farms that are not actively expanding at the moment.

Generally the farm-level risk coefficients listed below generate recognisable enterprise mixes. Stock farms grow lucerne, dry beans and token amounts of maize and generate good livestock mixes. Some lucerne hay is sold, and the rest feeds into livestock activities that, at this risk level, reflect the practice of combining veld and pasture to feed sheep and goats. The dairy model simulates the reported dairy system. Farm businesses have the most realistic mix of lucerne and maize at the current water constraint, and a typical mix of sheep goats and ostriches. The presence of ostriches in the farm business model is the reason for the ideal maize-lucerne ration. The failure to include maize as a feed component in sheep and goat activities is a possibly important weakness of the model. However, farmers were adamant that maize is not an important fodder crop for small stock.

Irrigation farms are not as well diversified as they should be at the selected risk aversion coefficients. Lucerne is the anchor crop for irrigation farms, but instead of rotating with maize, the model includes large areas under dry beans. The livestock mix emphasises sheep, especially sheep raised on pastures, which is typical for irrigation farms.

Moreover, generating a reasonable cultivar mix on citrus farms proved impossible at the present assumptions. The best success was achieved with large stable citrus units (type 14) where clementines and lemons could be limited to about 40 percent of total area. In all other cases the model insists on selecting only the significantly more profitable lemons in the optimal solution for a wide range of risk preferences.

Despite the weaknesses discussed here, the following risk aversion coefficients are included in all subsequent results. Irrigation farms are assumed to have a risk coefficient of 0.5 in the Upper Fish and 0.75 in the Middle and Lower Fish. Stockmen are assumed to be risk-averse in the Upper Fish (5) and Middle Fish (3) and similar to irrigators in the Lower Fish (0.7). Farm businesses are assumed to be risk-averse at coefficients of 2.5 in the Upper Fish and 4 in the Middle and Lower Fish. Dairymen are modelled to have a risk aversion coefficient of 0.25 in all areas. Large stable citrus farms (2.4) and small mixed farms (2.25) are assumed to be the most risk averse of farms in the Sundays River, while small expanding citrus farms (1.5) and large expanding citrus farms (1.8) are more risk neutral.

6.5. Risk adjusted production

Figures 6.3, 6.4, 6.5 and 6.6 compare farm level demand curves accounting for risk with the deterministic demand curves shown before. Risk adjusted demand is lower than demand curves which reflect the cost of bearing risk. Total water value is also lower as expected.

6.5.1. Upper Fish

At a risk aversion coefficient of 0.5, total water value for irrigation farms in the Upper Fish (type 1) falls from R20 291 to R4 648, but the shadow price at the present allocation increases from zero to R0.00108/m^3. The model selects significant lucerne component and a realistic livestock mix at a risk aversion coefficient of 0.5. The deterministic demand curve for type 1 is completely elastic up to a water constraint of 651 000m^3 while the risk adjusted demand curve shows a relatively inelastic response to price changes over the same range. The enterprise mix is stable throughout the range of water prices, and total irrigated area gradually expands as more water become available.

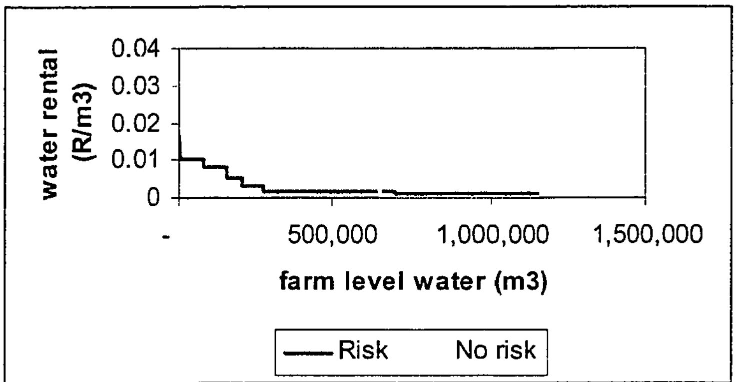
The most realistic enterprise mix for stock farms in the Upper Fish (type 2) is achieved at a risk aversion coefficient of 5.0. Total water value falls by about half from R20 291 to R10 009 at this risk level and the shadow price increases from zero to R0.0067/m^3. When accounting for risk lucerne is rotated with maize in the optimal solution. Maize and lucerne are sold and the livestock component consists of angoras on veld and sheep run a combination of pasture and veld. An interesting result of including risk on stock farms is that the veld-based extensive livestock system is not feasible without irrigation. The result is consistent with the local wisdom, which holds that fodder production has a stabilising effect on the extensive stock operation characteristic of the Karoo.

The risk-adjusted demand for water by a farm business in the Upper Fish at a risk aversion coefficient of 2.5 reduces water value from R328 113 to R33 423/year. The shadow price at the current allocation falls from R0.0468/m^3 to R0.0106/m^3. The model selects angoras on veld and wool sheep on a combination of pasture and veld. Ostriches do not inter into the optimal solution at any water level and crop mix consists of dry beans and lucerne, which is mostly sold as hay.

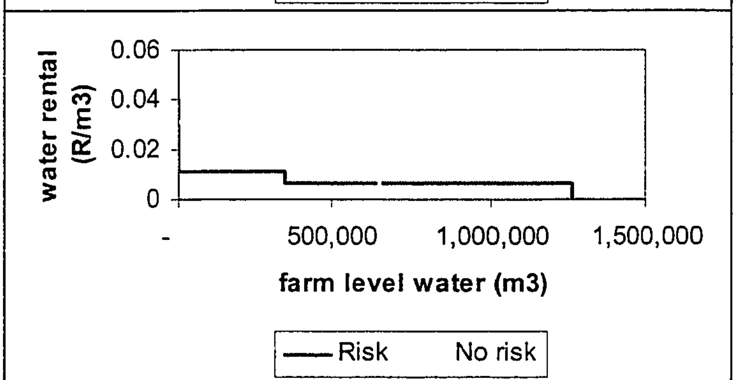
The most appropriate risk aversion coefficient for Upper Fish dairymen is 0.25. At this risk level, total water value falls from R108 283 to R76 757, which is the smallest adjustment for any farm in the region. It suggests that dairy farmers have very little opportunity to diversify. In fact, the risk coefficient only affects shadow prices up to a water constraint of 1 549 445m^3. Beyond 1.5 million m^3 the risk premium has no effect on shadow prices.

6.5.2. Middle Fish

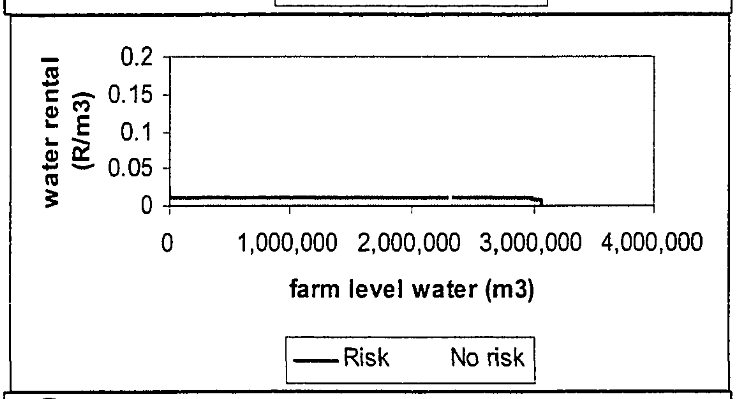
When including risk at a coefficient of 0.75 total water value falls from R57 418 to R2 238 for irrigators in the Middle Fish. The current water constraint is not binding and the model selects beans, lucerne, angoras and wool sheep. The very low total value and the zero marginal value of water suggest that Middle Fish irrigators will be the most likely sellers of water.



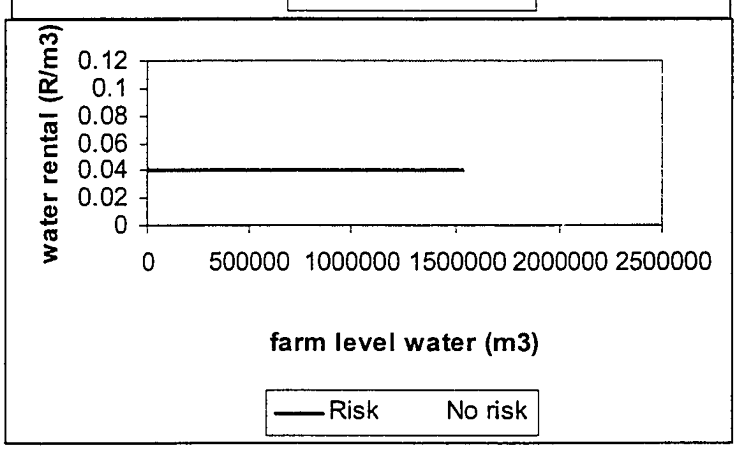
Type 1
UF irrigator



Type 2
UF stockman



Type 3
UF farm business



Type 4
UF dairy

Figure 6.3: Farm level water demand with and without risk for farm types 1-4

Stock farms in the Middle Fish are modelled to have a risk aversion coefficient of 3.00. As in the case of Middle Fish irrigators, the current water constraint is not binding when risk is included. Total farm level water value falls from R57 419 to R8 014 when risk is accounted for, making type 6 farms likely sellers of water as well. The optimal enterprise mix consists of lucerne and dry beans. The lucerne is fed to wool sheep that also uses veld for part of the year. Surplus hay is sold. As the water constraint is reduced, sheep is shifted to veld where they replace some angoras. Hay sales gradually decrease and disappear at a water constraint of 67 357m^3. Stock keeping without access to irrigation is feasible in the Middle Fish. At a water constraint of zero the livestock mix consists of two-thirds sheep and one-third angoras, which is about the observed stock mix for the region.

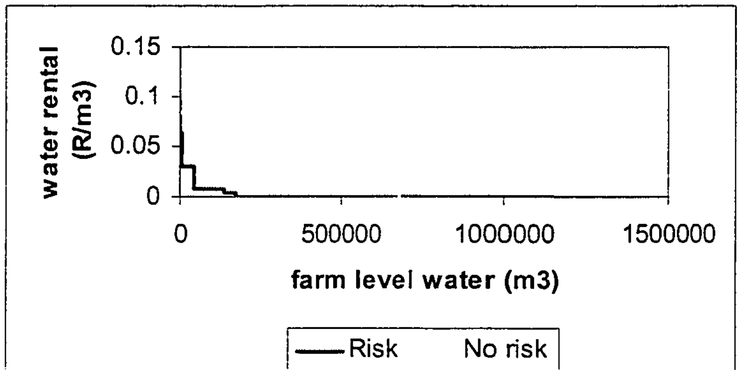
Farm businesses in the Middle Fish (type 7) are modelled to reflect a risk aversion coefficient of 4, compared to 2.5 in the Upper Fish. Total water value falls from R475 540 to R93 866 when risk is included in model 7, and the non-zero shadow price indicates that water is a binding constraint at the current allocation. Accounting for risk reduces marginal willingness to pay from R0.0447/m^3 to R0.0120/m^3 at the current quota. At the current quota enterprise mix of farm businesses is similar to that of stock farms in the Middle Fish, except for a small maize component that feeds into ostrich production. Angoras and wool sheep are kept on veld, and a combination of veld and pasture supports a small number of additional sheep. Type 7 farms do not sell lucerne or maize, or grow potatoes.

Middle Fish dairy is modelled to have a risk aversion coefficient of 0.25. When risk is introduced, total water value falls from R116 391 to R82 683 and the shadow price at the current water constraint goes down from R0.0634/m^3 to R0.0427/m^3. Again, risk makes no difference to shadow prices beyond a farm water constraint of 1 631 384m^3.

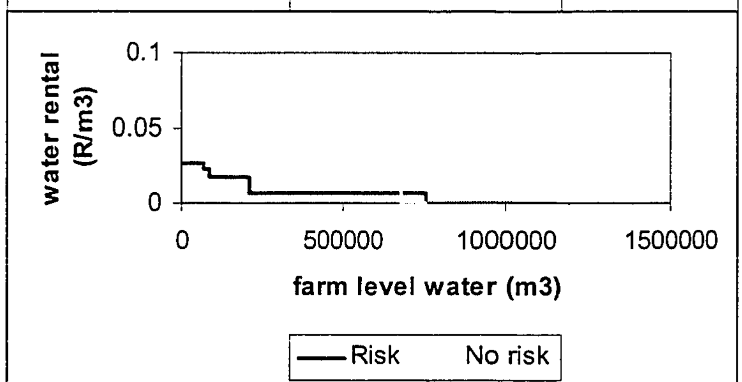
6.5.3. Lower Fish

Generally introducing risk has a more pronounced effect in models of the Lower Fish than in models of the Middle or Upper Fish. Total water value on irrigation farms in the Lower Fish (type 9) falls from R35 630 to R2 017 at a risk aversion coefficient of 0.75 due to very low levels of irrigation participation. At a result the current water constraint is not biding and type 9 farms may be potential sellers of water. The optimal solution combines lucerne with beans. When allowing for risk sheep comprise 40 percent of livestock, which is consistent with observations for the Lower Fish.

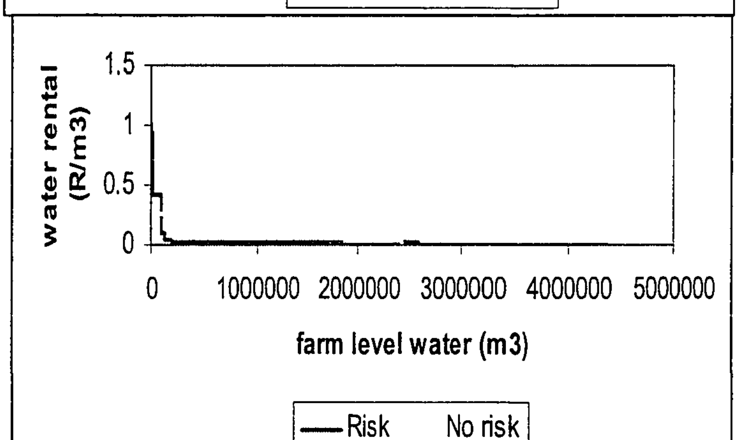
The most realistic enterprise mix for stock farmers in the Lower Fish is achieved at a risk aversion coefficient of 0.7, which is low compared to stock farmers elsewhere. Risk reduces total water value from R35 630 to R4 091, but the shadow price at the present quota increases from zero to R0.0014/m^3. Dry beans and lucerne are the only crops in the optimal solution and the livestock mix contains two-thirds angoras on veld. If the water constraint is reduced to zero the model selects only angoras on veld.



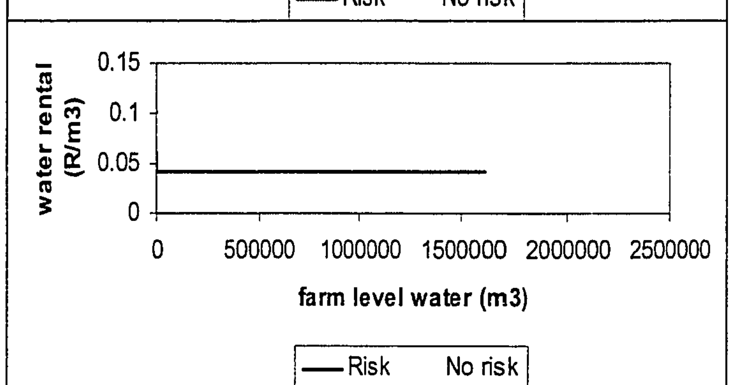
Type 5
MF irrigator



Type 6
MF stockman

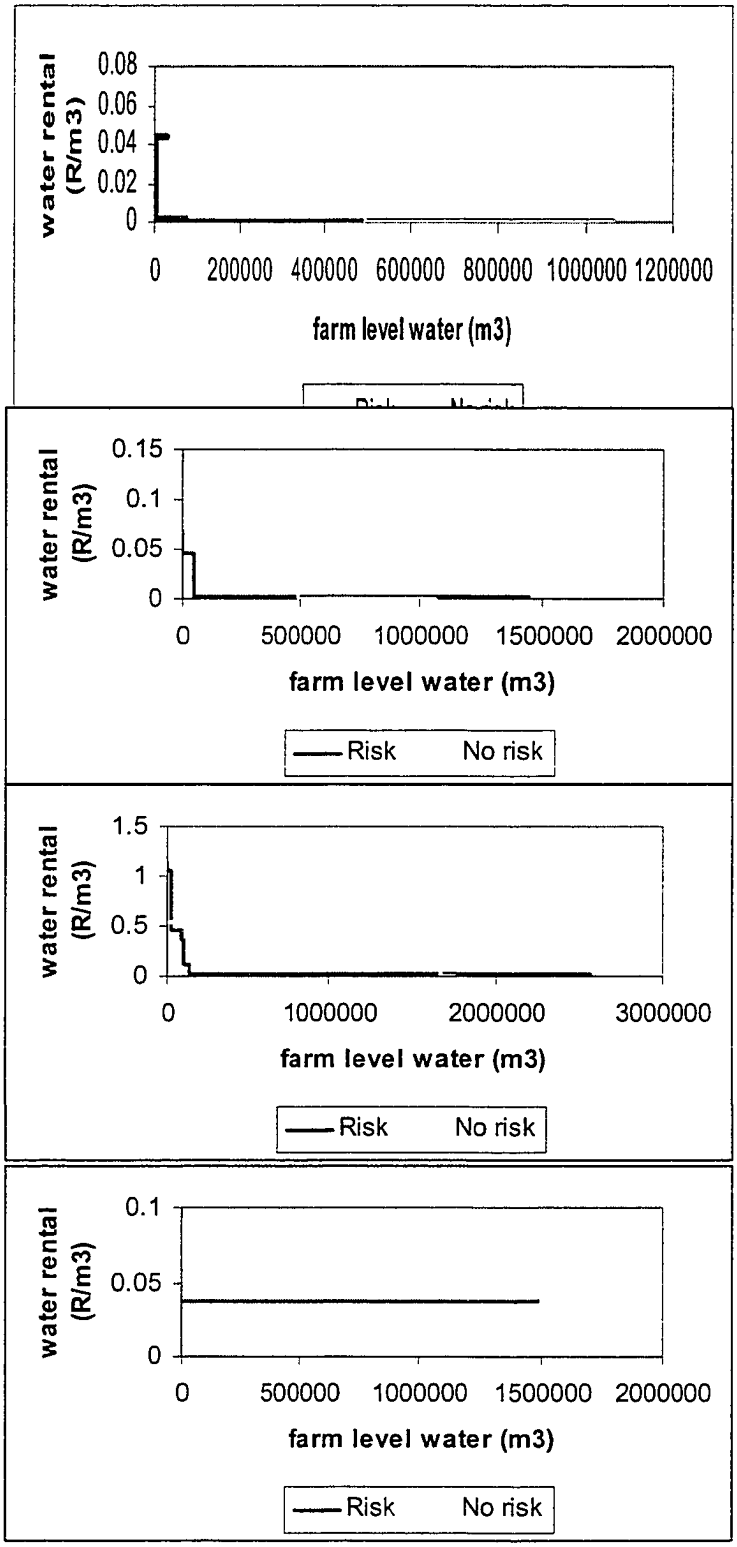


Type 7
MF farm business



Type 8
MF dairy

Figure 6.4: Farm level water demand with and without risk for farm types 5-8



Type 9
LF irrigator

Type 10
LF stockman

Type 11
LF farm business

Type 12
LF dairy

Figure 6.5: Farm level water demand with and without risk for farm types 9-12

If the risk aversion coefficient for farm businesses in the Lower Fish is assumed to be 4.00, farm-level water value decreases from R643 008 to R100 750. The current water constraint is binding and produces a marginal willingness to pay of R0.0163/m^3 when risk is introduced. The optimal solution includes lucerne, maize dry beans ostriches and wool sheep. Lower Fish farm businesses find it profitable to keep a combination of wool sheep and angoras when the water constraint is set to zero.

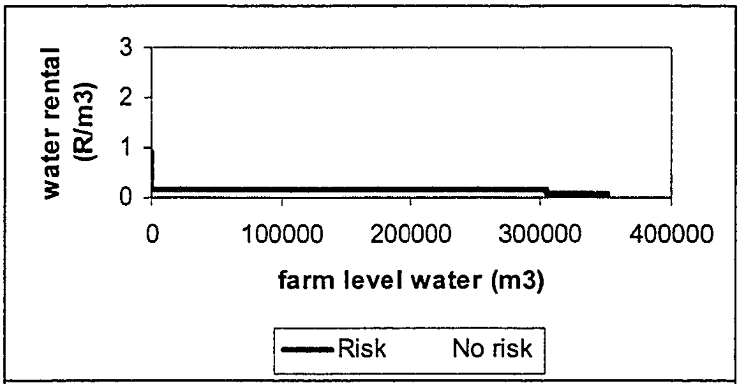
The pattern for dairy farms in the Lower Fish is similar than for the Upper and Middle Fish. Total water value falls from R98 383 to R64 675 at a risk aversion coefficient of 0.25. The present water constraint is binding and the shadow price at the current quota falls from R0.0611/m^3 to R0.0378/m^3 when risk is accounted for.

6.5.4. Sundays

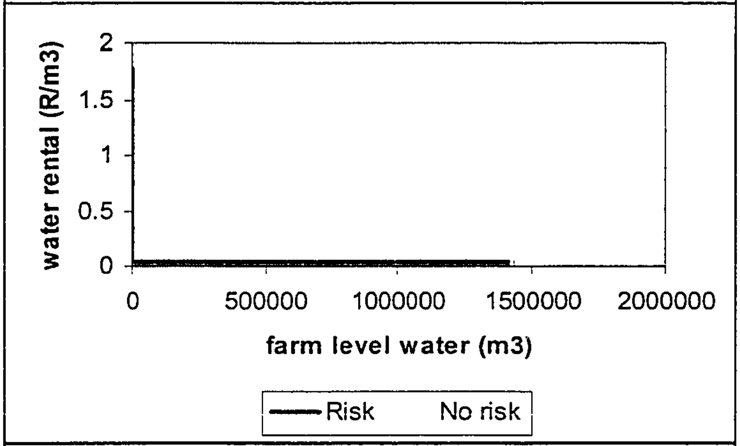
Figure 6.6 illustrates the effect of on water demand in the Sundays River. Under prefect certainty crop mix for types 13 to 16 are dominated by lemon production and cultivar mix is only endogenised at extremely high risk aversion coefficients. Thus the model fails to simulate a marginal water values that will attract water out of the Fish into the Sundays region. MOTAD is reasonably successful at simulate observed enterprise mixes for systems consisting of annual crops and livestock, but more work needs to be done on endogenising cultivar mix for tree crops.

The present approach seems to underestimate water values to citrus producers. Part of the reason for the difficulty is the range of citrus cultivar prices on which the simulation is based. Lemons is at a peak in its cycle, and downward adjusting lemon income by 20 percent is still not enough to allow other cultivars in the optimal solution. The only exception is large expanding citrus farms (type 14), where a reasonable cultivar mix was simulated although at the expense of a very low total water value. Replant rates are a crucial assumption for being able to endogenise cultivar mix in citrus production. Optimal solutions for the two expanding farms (type 15 and 16) could not be altered from lemons only at any risk level.

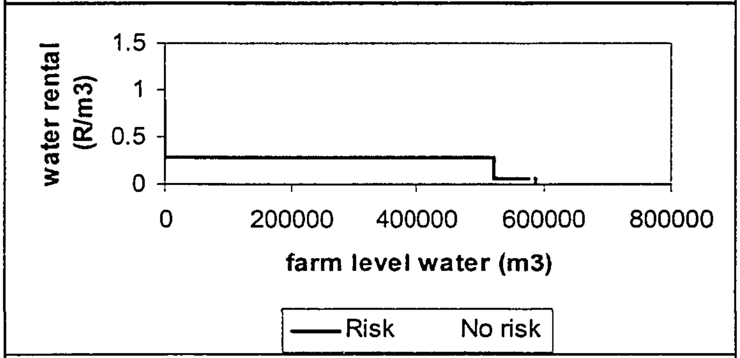
Type 13 is a small mixed farm that combines citrus, dairy and fodder production, and potatoes as an example of market vegetables. At a risk aversion coefficient of 2.25 farm-level water value falls from R598 841 to R49 510, which is still relatively high given the farm size. Marginal water values decreases from R1.6667/m^3 to R0.1525/m^3 at the binding farm level constraint. The optimal strategy in the face of risk is to combine lemons with potatoes. Dairy enters at higher risk aversion coefficients, but not at the selected risk level.



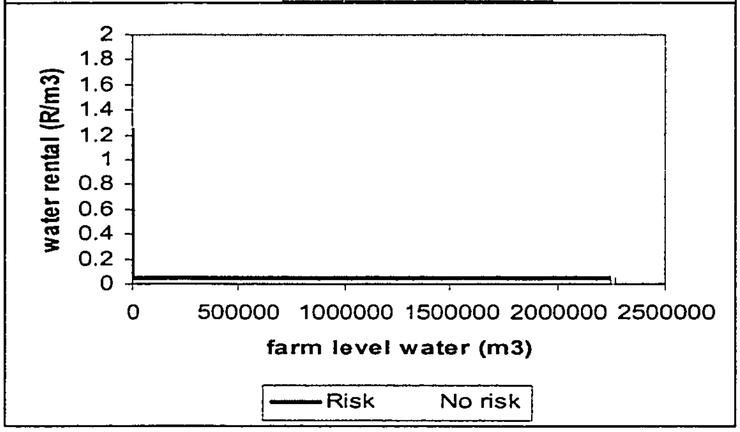
Type 13
small mixed



Type 14
large stable citrus



Type 15
small expanding citrus



Type 16
large expanding citrus

Figure 6.6: Farm level water demand with and without risk for farm types 13-16

A risk aversion coefficient of 2.4 approximately generates the observed cultivar mix for large stable citrus farms (type 14). This level of risk reduces farm-level water value from R2 605 880 to R50 359. In both cases the farm produces citrus only, and all citrus varieties have the same water requirement, the difference in water value is due to the risk premium reducing residual profits. At the present allocation level shadow prices falls from R1.8199/m^3 to R0.0352/m^3.

It is assumed that the strong growth of citrus area on small expanding citrus farms (type 15) is financed through vegetable production. At a risk aversion coefficient of 1.5 the optimal solution combines potatoes with lemons. No other citrus varieties are profitable. Total water value falls from R738 084 to R153 651 and the shadow price goes down from R1.2727/m^3 to R0.2862/m^3 when risk is included.

The risk aversion coefficient for large expanding citrus farms is assumed to be 1.80. At this risk level total water value falls from R2 878 527 to R98 442. The current water constraint is binding in both cases and the marginal willingness to pay, or water rental value, falls from R1.2727/m^3 to R0.0435/m^3. As a result of the rapid expansion rate that characterises large expanding farms lemons are the only feasible cultivar. Only token levels of navel oranges was simulated at relatively high risk coefficients.

6.6. Sensitivity analyses

In principle it is possible to do a sensitivity analysis for every parameter in the model. In practice model behaviour can be illustrated by a small number of carefully selected simulations. The following questions will illustrate the mechanics of the model or important policy implications:

1. What happens if risk aversion coefficients are standardised?
2. What happens is the objective function value for lemons is reduced by 25 percent?
3. What happens if the objective function value of maize is increased by 25 percent?
4. What happens if all objective function values increase by the same amount?
5. What happens if water tariffs increase?
6. What happens in labour costs rise?
7. What happens if irrigation systems efficiency increases?

6.6.1. Standard risk aversion coefficients

Despite theoretical justification for endogenising enterprise mix by introducing the cost of risk, the procedure for selecting the best-fit risk aversion coefficient has very little foundation. Table 6.9 summarises the risk aversion coefficients and total and marginal values at the current water quota used. There is a case to be made for assuming different risk coefficients for the different farm types, and even for a trend across regions. However, sizeable climate differences have been rejected on two accounts already, namely regarding farm sizes in table 5.10 and yield assumptions in table 5.11. Thus the sensitivity analysis is restricted to examining the effect of standardising risk coefficients for similar farms for the current water allocation.

Table 6.9: Best-fit risk aversion coefficients and water values for the Fish-Sundays scheme in 1999 Rand

Farm type	Risk aversion coefficient	Marginal water value (R/m^3)	Total water value (R/farm)
UF irrigation farm	0.5	0.0011	8,741
UF stock farm	5.0	0.0067	9,250
UF farm business	2.5	0.0106	21,189
UF dairy farm	0.25	0.0412	47,228
MF irrigation farm	0.75	0.0003	5,215
MF stock farm	3.0	-	19,347
MF farm business	4.0	0.0120	91,054
MF dairy farm	0.25	0.0427	49,016
LF irrigation farm	0.75	-	2,017
LF stock farm	0.7	0.0014	71,504
LF farm business	4.0	0.0163	125,098
LF dairy farm	0.25	0.0378	40,161
Small mixed farm	2.25	0.1525	39,811
Large stable citrus	2.40	0.0352	35,451
Small growing citrus	1.5	0.2862	128,797
Large growing citrus	1.8	0.0435	76,388

Farms that have fewer production possibilities are inherently more risky than farms on which it is possible to diversify. Therefore one would expect high coefficients to apply to stock farms and farm businesses and lower coefficients to produce the best results for irrigation farms, dairy farms and citrus farms. Furthermore, citrus farms with large non-bearing areas are more vulnerable to price and yield risk than farms that rely on a larger pool of income. This hypothesis is generally supported by the data in table 6.9, except for the inexplicably low value for stock farms in the Lower Fish (type 10). At a risk coefficient of 2.0 or 3.0 essentially the same result is generated, but under these assumptions the water constraint is not binding.

Table 6.10: Water values in 1999 Rand and enterprise mixes for irrigators and dairymen at the current water quota and risk coefficients of 0.25

	Irrigators			Dairy farms		
	Type 1	Type 5	Type 9	Type 4	Type 8	Type 12
Risk coefficient	0.25	0.25	0.25	0.25	0.25	0.25
Shadow price (R/m3)	0.0041	0.0000	0.0000	0.0412	0.0427	0.0378
Shadow price (R/ha)	55	-	-	556	577	472
Water value	8,741	37,770	15,982	47,228	49,016	40,161
Activity levels in optimal solution						
Dry beans flood std	17.20	85.00	85.00	NA	NA	NA
Dry beans laser improved	-	-	-	NA	NA	NA
Dry beans centre pivot	-	-	-	NA	NA	NA
Dry beans drag line	-	-	-	NA	NA	NA
Dry beans drip	-	-	-	NA	NA	NA
Maize flood std	0.00	-	0.00	-	-	19.18
Maize laser improved	-	-	-	20.24	19.12	-
Maize centre pivot	-	-	-	-	-	-
Maize drag line	-	-	-	-	-	-
Maize drip	-	-	-	-	-	-
Silage	NA	NA	NA	3.43	3.24	3.25
Harvest maize	0.00	0.00	-	16.82	15.88	15.93
Sell maize	-	0.00	0.00	-	-	-
Young lucerne flood std	6.16	-	-	0.00	0.00	-0.00
Young lucerne flood impr	0.00	-	-	6.39	6.10	6.12
Young lucerne centre pivot	-	-	-	-	-0.00	-
Young lucerne drag line	-	-	-	-	-	-
Young lucerne drip	-	-	-	-	-	-
Lucerne flood std	24.62	0.00	0.00	-	-	-
Lucerne flood improved	-	-	-	25.56	24.41	24.49
Lucerne centre pivot	-	-	-	0.00	-	-
Lucerne drag line	-	-	-	-	-	-
Lucerne drip	-	-	-	-	-	-
Sell lucerne	-	-	-	-	-	-
Rye grass flood std	NA	NA	NA	-	-	10.19
Rye grass flood improved	NA	NA	NA	10.76	10.16	-
Rye grass centre pivot	NA	NA	NA	-	-	-
Rye grass drag line	NA	NA	NA	-	-	-
Rye grass drip	NA	NA	NA	-	-	-
Ostriches	NA	NA	NA	NA	NA	NA
Sheep veld	-	-	-	NA	NA	NA
Sheep combination	-	-	-	NA	NA	NA
Target cells Sheep pasture	8.60	0.00	0.00	NA	NA	NA
Angora veld	1.34	1.34	1.34	NA	NA	NA
Angora combination	-	-	-	NA	NA	NA
Angora pasture	-	-	-	NA	NA	NA
Dairy cows				79.19	80.42	80.67
Hirelabour	53.36	105.55	117.19	57.02	55.33	57.53
OH Irrigation	47.98	85.00	85.00	62.95	59.79	59.98
OH Veld	256.00	256.00	256.00	NA	NA	NA

Table 6.11: Water values in 1999 Rand and enterprise mixes for stockmen and farm businesses at the current water quota and risk coefficients of 2.0

	Stockmen			Farm business		
	Type 2	Type 6	Type 10	Type 3	Type 7	Type 11
Risk coefficient	2	2	2	2	2	2
Shadow price (R/m3)	0.0000	0.0042	0.0000	0.0041	0.0163	0.0209
Shadow price (R/ha)	-	57	-	56	220	261
Water value	28,104	34,748	40,003	39,119	118,746	153,244
Activity levels in optimal solution						
Potatoes flood std	NA	NA	NA	-	-	-
Potatoes laser improved	NA	NA	NA	-	-	-
Potatoes centre pivot	NA	NA	NA	-	-	-
Potatoes drag lines	NA	NA	NA	-	-	-
Potatoes drip	NA	NA	NA	-	-	-
Dry beans flood std	5.06	25.55	21.26	9.71	57.04	6.53
Dry beans laser improved	-	-	-	-	-	-
Dry beans centre pivot	-	-	-	-	-	-
Dry beans drag line	-	-	-	-	-	-
Dry beans drip	-	-	-	-	-	-
Maize flood std	0.00	-	-	-	1.56	3.07
Maize laser improved	-	-	-	-	-	-
Maize centre pivot	-	-	-	-	-	-
Maize drag line	-	-	-	-	-	-
Maize drip	-	-	-	-	-	-
Silage	NA	NA	NA	NA	NA	NA
Harvest maize	-	0.00	0.00	-	1.56	3.07
Sell maize	-0.00	0.00	-0.00	-	-	-
Young lucerne flood std	5.74	5.42	2.92	11.00	8.12	10.88
Young lucerne flood impr	-	0.00	-	-	0.00	-0.00
Young lucerne centre pivot	-	-	-	0.00	0.00	-
Young lucerne drag line	-	-	-	-	-	-
Young lucerne drip	0.00	-	-	-	-	-
Lucerne flood std	22.95	21.69	11.67	44.02	32.47	43.51
Lucerne flood improved	0.00	-	-	0.00	-	-
Lucerne centre pivot	-	-	-	-	-	-
Lucerne drag line	-	-	-	-	-	-
Lucerne drip	-	-	-	-	-	-
Sell lucerne	154.83	-	-	234.97	-	-
Ostriches	NA	NA	NA	-0.00	6.51	12.80
Sheep veld	-	-	-	-	7.76	9.27
Sheep combination	12.36	6.27	11.27	25.02	29.01	37.40
Target cells Sheep pasture	-	5.65	-	-	-	-
Angora veld	6.56	11.69	9.44	28.70	20.09	17.07
Angora combination	-	-	-	-	-	-
Angora pasture	-	-	-	-	-	-
Hirelabour	48.00	77.29	62.79	111.85	170.36	133.97
OH Irrigation	33.75	52.67	35.85	64.73	99.19	63.99
OH Veld	2,540.00	2,540.00	2,540.00	7,900.00	7,900.00	7,900.00

Table 6.10 shows that for a standard risk coefficient of 0.25 diary farms have a larger unclaimed residual that can be interpreted as a total water value than irrigation farms. Marginal rental values for dairy farms are about R500/ha/year, while irrigation farms record a zero shadow price in the Middle and Lower Fish. In both cases beans are the only crop activity selected. The crop mix on irrigation farms suggests that water values are too high at this risk level.

At a standard risk coefficient of two, total water value for stock farms in the Upper and Middle Fish increased, but the water constraint is non-biding for all practical purposes in both cases and the crop mix is heavily biased towards beans. The lucerne hay activity disappears from the optimal solution for the Middle Fish. At a risk coefficient of 2.0 the water constraint in the Lower Fish is non-binding but crops appear in roughly the same proportions as before.

Farm businesses generate the highest marginal values of water in the Upper, Middle and Lower Fish and produce optimal solution similar to observed farming patterns. The resulting water values are therefore potentially the best estimate of water values for the region. At a risk coefficient of 2.0 the optimal solution for farm businesses consists includes beans, lucerne and maize. Hay sales are simulated for the Upper Fish, while ostriches enter into the solution for the Middle and Lower Fish. In all three cases, the model emphasises stock activities, and use cropping to support animals, which is characteristic of the area.

From the evidence in tables 6.10 and 6.11 one can conclude that there is no particular advantage in terms of crop mix or the resulting water values to standardise risk coefficients. The only exception concerns stock farms. If one restricts the risk coefficient on stock farms to 2.0, which is the highest level reported for MOTAD models in the literature, total water values increases significantly while shadow prices and enterprise mixes remain about the same as before.

6.6.2. Reduced lemon incomes

Table 6.8 shows that the optimal solutions of the citrus models feature lemons only since this variety is so much more profitable than any of the other cultivars are. Table 6.12 presents the results of the sensitivity analysis on lemon prices for three risk levels. Gross margin of full bearing lemons is reduced by 25 and 50 percent, and optimal solutions calculated for risk coefficients of 0.25, 1 and 1.5 at the current water quota. Lower lemon income reduces marginal and total values of water across all types and risk profiles, but for some farm types are affected more severely than others are. Very realistic citrus cultivar mixes are simulated in some cases.

A 25 percent reduction in gross margin for small mixed farms (type 13) leads to an optimal solution that only includes lemons at higher risk coefficients of 0.25. At a risk coefficient of one, lemons are combined with navels in roughly the observed proportions and at a risk coefficient of 1.5 a large share of potatoes are introduced. Risk-averse farmers place a marginal value of R0.1702/m^3, or R1 531/ha, on water. Total water value for type 13 farms at a 25 percent reduction is lemon income is R44 413 at a risk coefficient of 1.5. Lemons disappear from the optimal solution at all three risk levels if the gross margin of lemons is reduced by half. Shadow prices are somewhat lower without lemons than in the case of the 25 percent reduction.

As in the case of type 13 farms the best cultivar mix results are achieved with the scenario combining a 25 percent reduction in gross income of lemons with a risk aversion coefficient of 1.5. In this scenario lemons contribute about 10 percent of bearing area, with the rest split between navel and valencia oranges. Resulting marginal water values are R0.2115/m^3, or R1 904/ha/year, which still represents about a 75 percent return on investment in water rights at a purchase price of R2 500/ha.

For small expanding citrus farms (type 16) the optimal solution at a risk coefficient of 0.25 and lemon income level reduced by 25 percent still contains lemons only. At the higher risk levels lemons are combined with potatoes as in the case of type 13 farms. When the objective function value of lemons is reduced by 50 percent lemons disappear from the optimal solution at all three risk coefficients are replaced by navel oranges. The scenario combining a 25 percent reduction in lemon income with a risk aversion coefficient of 1.5 produces marginal water values of R0.0815/m^3, or R733/ha, which still represents a 30 percent return on investment.

Large expanding citrus farms are the most severely impacted reductions in lemon income. At a risk coefficient of 1.5 a 25 percent reduction in lemon income discontinues production. If the gross margin of lemons is reduced by 50 percent only the least risk-averse scenario is feasible. A 25 percent reduction in income and a risk coefficient of 1.0 produces an optimal solution that includes other varieties besides lemons, and produces a marginal water value is R0.2142/m^3, or R1 928/ha, which is similar to the value calculated for large stable citrus farms.

The best results are obtained by decreasing the objective function value for lemons by 25 percent, and standardising to risk coefficients of 1.5. The resulting marginal water values are on the high side, but not unrealistic compared to water values in the Upper, Middle and Lower Fish or compared to municipal bulk water rates of R1.26 /m^3. The results in table 6.12 are used for aggregation purposes.

6.6.3. Increasing gross margins for all crops

A change in gross margin is important from a policy point of view since it simulates potential impacts of increasing yield through extension efforts, the effects of a decline in farm prices, or the results of an exchange rate collapse where a significant portion of farm inputs are imported.

Table 6.12: Effects of reducing lemon gross margin by 25% and 50% at three risk coefficients for citrus farms in the Sundays

Type 13: Small mixed farms						
Reduce lemons' gross margin by	25%	25%	25%	50%	50%	50%
Risk aversion coeff	0.25	1	1.50	0.25	1	1.50
Shadow price (R/m3)	0.8726	0.3827	0.1702	0.7545	0.3074	0.1528
Shadow price (ha equiv.)	7,854	3,444	1,531	6,791	2,767	1,375
Total water value (R/farm)	227,755	99,885	44,413	196,926	80,235	39,884
Activity levels in optimal solution						
Year 1 trees	0.84	0.84	0.32	0.84	0.59	0.63
Year 2 trees	0.84	0.84	0.32	0.84	0.59	0.63
Year 3 trees	0.84	0.84	0.32	0.84	0.59	0.63
Navels	-	10.19	2.26	18.54	13.01	4.60
Lemons	18.54	8.35	4.84	-	-	-
Clementines	-	-	-	-	-	-
Valencias	-	-	-	-	-	9.22
Dairy cows	0.00	-	-	-	0.00	0.00
Rye grass flood std	-	-	-	-	-	-
Rye grass flood improved	-	-	-	-	-	0.00
Rye grass drag line	-	-	-	-	-	-
Rye grass drip	0.00	0.00	-	-	-0.00	-
Young lucerne flood std	0.00	0.00	-0.00	-0.00	-	-
Young lucerne flood impr	-	-	0.00	0.00	-	0.00
Young lucerne drag line	0.00	0.00	0.00	0.00	0.00	0.00
Young lucerne drip	-	0.00	0.00	0.00	0.00	0.00
Lucerne flood std	-	-	-	-	-	-
Lucerne flood improved	-	-	-	-	-	-
Lucerne drag line	-	-	-	-	-	-
Lucerne drip	-	0.00	0.00	0.00	-	-
Sell lucerne	-	-	-	-	-	-
Potatoes flood std	-	-	-	-	-	-
Potatoes laser improved	-	-	17.51	-	-	7.22
Potatoes drag lines	-	-	-	-	-	-
Potatoes drip	-	-	-	-	11.72	-
Hirelabour	74.76	59.62	78.50	47.22	66.00	55.58
OH Irrigation	21.07	21.07	16.82	21.07	20.65	19.31

Type 14: Large stable citrus farms						
Reduce lemons' gross margin by	25%	25%	25%	50%	50%	50%
Risk aversion coeff	0.25	1	1.50	0.25	1	1.50
Shadow price (R/m3)	0.9979	0.4907	0.2115	0.8756	0.3764	0.2038
Shadow price (ha equiv.)	8,981	4,416	1,904	7,880	3,388	1,834
Total water value (R/farm)	1,005,847	494,646	213,221	882,599	379,413	205,463
Activity levels in optimal solution						
Year 1 trees	1.58	1.58	1.58	1.58	1.58	1.58
Year 2 trees	1.58	1.58	1.58	1.58	1.58	1.58
Year 3 trees	1.58	1.58	1.58	1.58	1.58	1.58
Navels	-	40.73	18.01	74.11	39.82	22.16
Lemons	74.11	33.39	8.22	-	-	-
Clementines	-	-	-	-	-	-
Valencias	-	-	47.89	-	34.29	51.95
Hirelabour	293.33	232.82	187.26	183.21	177.37	174.36
OH Irrigation	78.84	78.84	78.84	78.84	78.84	78.84

Table 6.12 cont.

Type 15: Small expanding citrus farms						
Reduce lemons' gross margin by	25%	25%	25%	50%	50%	50%
Risk aversion coeff	0.25	1	1.50	0.25	1	1.50
Shadow price (R/m3)	0.5401	0.2142	0.0815	0.4312	0.1484	0.0057
Shadow price (ha equiv.)	4,861	1,928	733	3,880	1,335	51
Total water value (R/farm)	243,058	96,388	36,665	194,023	66,770	2,543
Activity levels in optimal solution						
Year 1 trees	3.10	1.03	0.86	3.10	1.11	0.93
Year 2 trees	3.10	1.03	0.86	3.10	1.11	0.93
Year 3 trees	3.10	1.03	0.86	3.10	1.11	0.93
Navels	-	-	-	29.49	10.50	8.80
Lemons	29.49	9.79	8.16	-	-	-
Clementines	-	-	-	-	-	-
Valencias	-	-	-	-	-	-
Potatoes flood std	-	-	-	-	-	26.40
Potatoes laser improved	-	32.68	35.38	-	31.50	-
Potatoes drag lines	-	-	-	-	-	-
Potatoes drip	-	-	-	-	-	-
Hirelabour	124.36	140.63	141.98	80.55	124.44	106.11
OH Irrigation	38.80	29.22	28.43	38.80	29.56	24.78

Type 16: Large expanding citrus farms						
Reduce lemons' gross margin by	25%	25%	25%	50%	50%	50%
Risk aversion coeff	0.25	1	1.50	0.25	1	1.50
Shadow price (R/m3)	0.540130	0.088164	-	0.431163	-	-
Shadow price (ha equiv.)	4,861	793	-	3,880	-	-
Total water value (R/farm)	947,928	154,727	0	756,692	0	0
Activity levels in optimal solution						
Year 1 trees	12.11	12.11	0.00	12.11	0.00	0.00
Year 2 trees	12.11	12.11	0.00	12.11	0.00	0.00
Year 3 trees	12.11	12.11	0.00	12.11	0.00	0.00
Navels	-	63.20	0.00	115.00	0.00	0.00
Lemons	115.00	51.80	0.00	-	0.00	0.00
Clementines	-	-	-	-	-	-
Valencias	-	-	-	-	0.00	0.00
Hirelabour	485.02	391.13	0.00	314.16	0.00	0.00
OH Irrigation	151.31	151.31	0.00	151.31	0.00	0.00

Yield, price and the cost of production have similar effects on derived demand for water. Yield and price affect total income, from which cost of production is subtracted to compute the contribution of a given activity to the objective function. Increases in product price or yield and decreases in production costs will increase water demand, and vice versa. If the objective function value of all activities is changed by the same amount, the optimal solution will be unchanged, but it was illustrated for lemons that if the gross margin of a single activity is changed, a new optimal solution emerges. Since water value is defined as the Ricardian residual, a small change in objective function value leads to a large change in the resulting water value. Once a market for water is implemented, the resource will no longer be the residual claimant, so that water values will not fluctuate as wildly as the model suggests. However, the conclusion remains, namely that production cost rises, willingness to pay for water falls to zero.

Two scenarios are examined for farm type 15, small expanding citrus farms in the Sundays River. The objective function values for bearing citrus and potatoes were increased and decreased by 10 percent each. Figure 6.7 shows the resulting rise and fall in total and marginal water values.

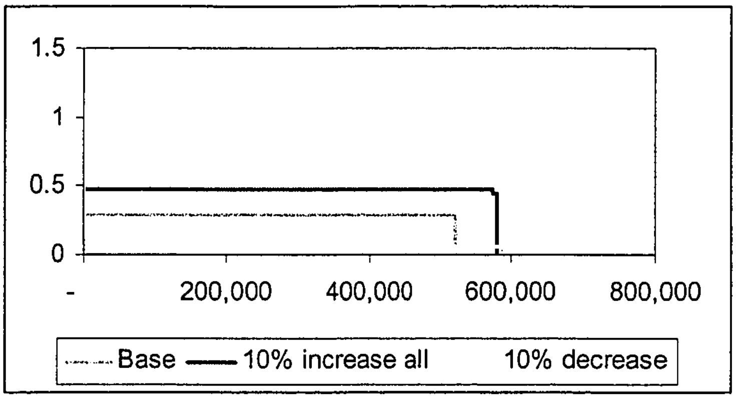


Figure 6.7: The effect of a 10% change in objective function values for small expanding citrus farms in the Sundays River

At the current allocation a 10 percent increase in objective function values leads to a 65 percent increase in marginal value and total value rises by R120 713 at 600 000m^3. A 10 percent decrease causes marginal values to fall by 55 percent at the current allocation, and reduces total farm-level water value by R83 944 at a water constraint of 600 000m^3. Similarly any cost of production decreases marginal water value and any increase in price or yield increases marginal and total values.

6.6.4. Changing water tariffs and other overheads

Water tariffs operate like any other component of overheads, but are interesting since tariffs are the Department of Water Affair and Forestry's preferred policy instrument. Recall that the at the moment water tariffs are levied as a flat rate regardless of use. As such it is no different from returns to management or land. Returns to fixed factors are subtracted from total model profits per unit of land used for crop and livestock activities.

Total profits fall if water tariffs, or other returns to fixed factors, increase. The demand curve shifts downwards, reducing total water value. To illustrate the effects of increasing returns to fixed factors the objective function value of the "overheads" activity are increased and decreased by 10 percent respectively for Middle Fish dairy farms. A decrease in overheads increases total water values to R97813, and raising overheads by 10percent reduces water values to R67553.

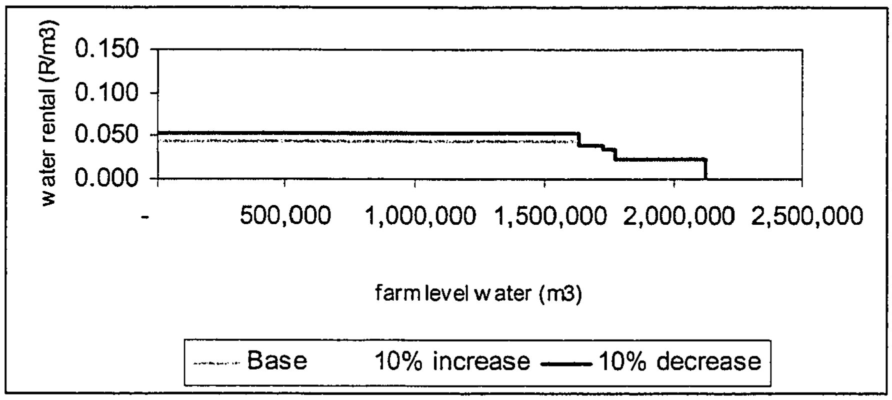


Figure 6.8: The effect of a 10% change in water tariffs on farm-level water demand for dairymen in the Middle Fish

Three policy implications must be noted regarding the possibilities for increasing water rates. It is a generally accepted among agricultural economists that while farms are fairly similar in terms of production cost structures and yields, and by implication gross margins, they differ significantly when it comes to debt. It is not so much a matter of finding an accurate estimate of overhead cost, as it is a matter or inherent differences among farmers. Some farmers, given their debt load, will be able to survive for example a threefold increase in water tariffs while others will go out of business. The second important policy implication regards scheme-wide cost-benefits analysis. Total benefit decreases directly by the amount of increased water rates. This implies that scheme costs net of any water rates must be used on the cost side to account for all benefits. The third policy implication is that the way water is charged for by the Department of Water Affairs and Forestry does not provide an incentive to reduce use levels or to substitute from water-using to water-saving irrigation technology. Increases in water rates affect shadow prices of water, but not the farming system, and therefore not the range of quantities for which the holds. The water demand curves in this chapter show the responsiveness of quantity demanded to volumetric pricing, providing evidence that farmers will reduce quantity demanded if a volumetric water rate is implemented.

6.6.5. Changing agricultural wages

Agricultural wages in South Africa have increased rapidly since 1994, and are still the target of further policy intervention. Mechanically labour costs are treated like any other cost of production, but as a result of the labour saving nature of most water saving irrigation systems, an increase in labour cost could change the relative factor prices such that labour saving systems become feasible. It is therefore possible to influence water use through labour policy. At the very least these to interventions should not be attempted in isolation of each other.

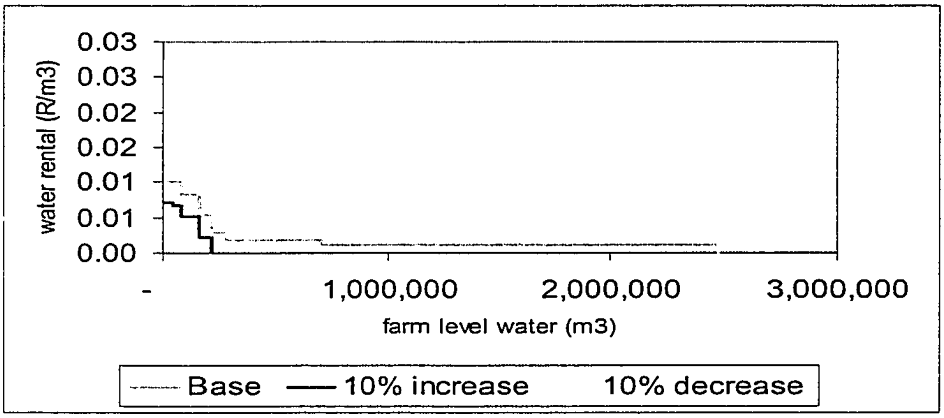


Figure 6.9: The effect of a 10% change in wage rate on farm-level water demand for irrigators in the Upper Fish (type 1)

Figure 6.9 compares the effects of a 10 percent increase in wages and a 10 percent decrease in wages for irrigators in the Upper Fish. The decrease in wages increased total water value by one third from R10 009 to R13 414. Optimal enterprise mix did not change in this case as a result of a change in the wage rate. Standard flood irrigation is still the preferred technology at all but the most binding water constraints.

The impact of a wage increase is even more striking and far more important from a policy point of view. Farm wages are likely to increase rather than decrease in the near future. Figure 6.9 clearly shows that if the wage bill for Upper Fish irrigators increase by as little as 10 percent irrigation possibilities, and the resulting demand for water, are severely reduced.

6.6.6. Irrigation systems efficiency

It is typical of the simulations presented here that standard flood irrigation remains optimal over a wide range of water quantities. This raises the question of how sensitive the optimal solution is for the water use intensity of different irrigation systems. If systems efficiency of the entire suite of technologies is improved at the same time, water will become less of a binding constraint and associated shadow prices will fall. A more interesting question to explore is whether a 25 percent decrease in the systems efficiency of standard flood irrigation will remove it from the optimal solution, and what effect such a result may have on farm level water demand.

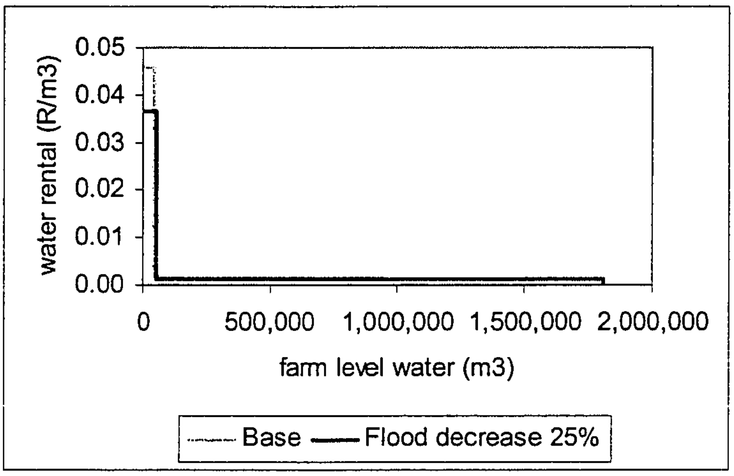


Figure 6.10: The effect of a 25% reduction in systems efficiency of flood irrigation for stock farms in the Lower Fish (type 10)

The experiment in figure 6.10 provides several interesting insights. The first is that flood is still the most profitable irrigation technology when its systems efficiency is reduced by 25 percent. Secondly, water demand curves become more inelastic as systems efficiency improves, generating a result identical to changing the water constraint within the range of a basis change. Thirdly, the total area under the demand curve remains unchanged because no prices where affected. Quantities shift out and the corresponding shadow prices decrease to keep total farm level water value constant at R4 091.

6.7. The value of water to commercial irrigation

The total value of irrigation water to commercial farmers in the Fish-Sundays scheme is reported in table 6.13. Values are in 1999 Rand, and reflect risk adjusted farm-level production at the current water constraint. For types 1-12 the farm-level values reported in table 6.9 were used as a basis for aggregation and for the citrus farms the data in table 6.12 were used. A 25 percent decrease in the objective function and a risk coefficient of 1.5 are assumed for all types.

Table 6.13: The value of water to commercial irrigators in the Fish-Sundays scheme at present allocation levels

Representative farm		Total value Rand/farm	Aggregation factor	Regional values by type 1999 Rand
Type 1	UF irrigator	8,741	65	568,165
Type 2	UF stockman	9,250	53	490,250
Type 3	UF farm business	21,189	9	190,701
Type 4	UF dairyman	47,228	-	-
Type 5	MF irrigator	5,215	29	151,235
Type 6	MF stockman	19,347	25	483,675
Type 7	MF farm business	91,054	15	1,365,810
Type 8	MF dairyman	49,016	16	784,256
Type 9	LF irrigator	2,017	66	133,122
Type 10	LF stockman	71,504	36	2,574,144
Type 11	LF farm business	125,098	36	4,503,528
Type 12	LF dairyman	40,161	18	722,898
Type 13	Small mixed	44,413	111	4,929,843
Type 14	Large stable citrus	213,221	33	7,036,293
Type 15	Small growing citrus	36,665	82	3,006,530
Type 16	Large growing citrus	-	18	-
	Total commercial irrigation			26,940,450

Value per farm type is aggregated based on the share of a particular type in the region as reported in the irrigation surveys. The aggregation factor for type 1 means that there are 65 irrigation farms in the Upper Fish. The regional contribution to water value by irrigators in the Upper Fish is R568 165. Stock farms contribute the largest value in the Upper Fish, while relatively small numbers of farm businesses generate the highest total water values in the Middle and Lower Fish regions.

Total water value increases from the Upper to the Middle to the Lower Fish, partly as a result of a zero response of dairy farms in the sample of Upper Fish irrigators, but also as a result of the total irrigated area in the three regions. Farm businesses contribute the highest water values, followed by dairy farms. The total value of commercial irrigation is just under R27 million in 1999 rands, of which the Sundays River citrus producers contribute just over 55 percent.

The implication of the classification of regional values is that from an efficiency point of view the resource should be allocated to citrus production. Except for large expanding citrus farms (type 16), which at the assumed expansion rate and risk profile are not profitable, marginal values confirm that citrus producers are willing to pay more for water than any other type. Shadow prices range between R733/ha and R1 904/ha compared to the highest value in the Fish River of R576 recorded by dairy farms in the Middle Fish. The results therefore confirms the hypothesis that allocative efficiency can be improved by allowing water to migrate from the Upper, Middle and Lower Fish to the Sundays River.

While large expanding citrus farmers have been the main purchasers of water in the recent past, their ability to pay is extremely low while waiting for the new developments to come into production. Once the orchards generate an income, and expansion rates slow down, ability to pay within type 16 will be closer to that of large stable citrus farms than zero. As a result total water value, as defined as the residual should increase over time, ceteris paribus, when the difference in shadow prices is likely to stimulate further reallocations.

CHAPTER 7: AGRICULTURAL DEMAND FOR SMALL-SCALE IRRIGATION

7.1. Introduction

The discussion of the water balance in Chapter 3 showed that a small portion of the water in the Fish-Sundays transfer scheme is currently allocated to the Tyefu tribal community in the lower reaches of the Great Fish River. From an efficiency point of view this user group is too small to matter, but in the South African situation formerly disadvantaged stakeholders are more important than their present use levels suggest. It is not clear what the trade-offs between small-scale tribal and commercial irrigation are, and how best to achieve an equitable redistribution, but the National Water Act (Act 36 of 1998) is quite clear about its purpose:

> "The purpose of this Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors -
>
> *(a)* meeting the basic human needs of present and future generations;
> *(b)* promoting equitable access to water;
> *(c)* redressing the results of past racial and gender discrimination;
> *(d)* promoting the efficient, sustainable and beneficial use of water in the public interest;
> *(e)* facilitating social and economic development; ...
>
> and for achieving this purpose, to establish suitable institutions and to ensure that they have appropriate community, racial and gender representation. "
>
> Republic of South Africa, 1998

Objectives (a), (b) and (c) are concerned with equity, and (d) and (e) emphasise efficiency. The allocation issues in the rest of the basin can be argued almost entirely on efficiency grounds, but for the Tyefu traditional community efficiency may not be sufficient grounds for access.

Binswanger and Elgin (1990) argue that redistribution to smallholders is only appropriate if redistribution increases total output. Chapter 7 tests the small-scale efficiency hypothesis. It starts off with a brief history of irrigation at Tyefu, drawing from various reports, and then presents an efficiency analysis based on the work of Van Averbeke et al (1998) and Bembridge (2000). It also includes the case of American Indian Water Rights as a comparison for the South African case.

7.2. Tyefu's irrigation history

It took about ten years to investigate the feasibility of bulk water provision to the Tyefu area. At the time an irrigation pilot project adapted production systems to local conditions and introduced the community to small-scale irrigation farming. For various reasons the project never developed much beyond the pilot stage. More importantly, the initial positive reports have lately been replaced by analyses suggesting project failure.

7.2.1. Infrastructure development

Several engineering and irrigation feasibility studies were carried out since the mid 1970s (Directorate of Water Affairs, undated; Development Bank of South Africa, undated; Ciskeian Government Services, 1981; Department of Agriculture and Rural Development, 1987). Engineering feasibility reports recommend "further economic evaluation of the irrigation scheme", and also request specifically that the silt load of the river and water rights be investigated (Directorate of Water Affairs, undated).

The first report suggests one of two alternatives, namely an "off-channel storage dam with canal system", and an "in-channel storage dam with bypass and canal system" (Directorate of Water Affairs, undated). The in-channel project was rejected for salinity reasons. Further work identified the most optimal off-channel storage site (Ciskeian Government Services, 1981). Local distribution from the off-channel reservoir (Glen Melville Dam) would take place via a system of pipelines and canals, which only still extends to about half the area developed in the pilot project. The rest of the pilot project was supplied expensive pumping directly from the river. Pumping was discontinued in 1995 (Van Averbeke et al, 1998).

7.2.2. Early performance of the irrigation project

The agricultural feasibility reports are consistently positive. They identify about 4 619ha moderately high potential irrigable land, and list citrus, maize, legumes, cotton and vegetables as suitable crops (Development Bank of Southern Africa, undated; Department of Agriculture and Rural Development, 1987).

It is remarkable that the feasibility reports emphasise vegetable production instead of focussing on maize and livestock systems, which are more typical in the region. Commercial experience at the time of the feasibility studies shows that tobacco, cotton, citrus and vegetables can be produced in the area, but that lucerne fits best with livestock. Commercial farmers rejected cotton because it is unprofitable and discarded citrus and tobacco for water quality reasons.

Much of the hopeful tone of the agricultural feasibility reports was due to the success of a pilot project. Van Averbeke et al (1998) provides a detailed account of the project's development. The project took the form of an out-grower scheme organised around a central estate that provided inputs (including marketing services), project management and training to surrounding out-growers. Apart from the central estate, three large tribal farms provided agricultural wage employment and two classes of smallholdings catered for small commercial farmers and subsistence needs. The goal with the commercial plots was to cater for "a middle class farmer firmly entrenched in [the] cash economy", but experience suggests that commercial farmers are just more well-endowed foodplot holders (Bembridge, 2000). Table 7.1 lists the project's share of each farm type.

Table 7.1: Share of farm units on the Tyefu irrigation project

	1984		1998	
Description of unit	**Number**	**Area (ha)**	**Number**	**Area (ha)**
Fooplots (0.25 ha each)	224	56	223	56
Foodplots (0.20 ha)	-	-	547	109
Foodplots (0.16 ha)	-	-	717	115
Small commercial (4 ha)	30	120	32	136
Tribal farms	3	201	-	-
Central estate	1	96	1	228
Total project		473		644

Source: Department of Agriculture and Forestry Ciskei, 1984 and Van Averbeke et al, 1998

The crops grown on the pilot scheme included maize, a wide variety of market vegetables and lucerne (Ciskeian Government Services, 1981). Vegetables had to be grown according to strict and explicit instructions, and in return farmers had a ready outlet for their produce with the central estate where vegetables were sorted, packaged and processed. Sprinkler irrigation was used, and electricity for pumping was supplied by the Ciskeian Government free of charge.

The pilot project report admits that pumping cost renders the agricultural project unprofitable, but argues that social benefits outweigh the economic loss made on agriculture. Besides, at the time it was still expected that pumping would be replaced by a low cost gravity system directly from the dam.

The most widely recognised benefit of the project was rural employment creation. The need for rural employment is consistent with Natrass and May (1986) who found that household income in rural communities in KwaZulu was directly proportional to number of migrants in the family. The Tyefu project paid out about R350 000 (Rand 1985) in wages in 1985 and provided between 150 and 200 full time jobs as well as 1 200 part time jobs (Bembridge, 1986; Department of Agriculture and Rural Development, 1987). The pilot project significantly reversed the phenomenon of male absenteeism, thereby contributing to a more sustainable rural community. Other benefits listed are subsistence food production, cash incomes and vocational training in agriculture (Department of Agriculture & Forestry Ciskei, 1984).

While employment is clearly a key benefit, it is possible to over-estimate the employment potential of the irrigation project. Any alternative employment in the area will draw away labour from the project, if agriculture is not the first choice of industry to work in. This may lead to labour shortages that may be a binding constraint during a critical harvesting season:

> "In planning the future agricultural production programmes cognisance must be taken of [the limited nature of the casual labour force] together with the fact that employment in the agricultural sphere is not preferred and has a low preference rating. With this in mind a settled, stable labour force will only be established if it can be offered regular employment with housing and a full range of social services not normally associated with employment in [commercial] agriculture."
>
> Department of Agriculture and Rural Development, 1987

The idea that agriculture may not be the first choice employer of rural workers is echoed by Bembridge (1986), who calls for an incentive system that will allow the small-scale commercial farmers to earn incomes commensurate with employment in the urban sector.

7.2.3. Recent performance of the Tyefu irrigation project

Table 7.1 also lists the current composition of holdings in Tyefu. Total area expanded somewhat in the last fifteen years, but the irrigation project clearly did not reach its full potential of 3 000ha. The tribal units have been converted to foodplots when the management company (Ulimocor) withdrew in 1995. Instead of the original 0.25ha foodplots, average plot size is now 0.19ha (Van Averbeke et al, 1998). When Ulimocor withdrew, the out-grower system collapsed bringing production to a halt. A contributing factor to the collapse was that free pumping was discontinued at the same time. This meant that water supplies were cut off unless smallholders were able to afford an annual pumping cost of about R200 per plot (Bembridge, 2000).

Bembridge (2000) describes the pre1995 production system and farmer perceptions in detail, and Van Averbeke et al (1998) also provide some valuable data. The economic analysis presented below relies on the data in these two sources, since there is no functioning production system to study at the moment.

Commercial smallholders grew maize, baby carrots for canning purposes and cabbage while foodplot holders produced maize, cabbage, potatoes, spinach and beetroot. Both groups produced primarily for home-consumption, and sold the surplus (Bembridge, 2000). The strong emphasis on maize is typical of small-scale crop production traditional rural communities in South Africa. A few head of cattle, some goats and pigs and poultry were also kept for subsistence purposes.

7.2.4. Conditions for success

While the majority of focus groups interviewed by Bembridge (2000) were willing to admit that the project improved their standard of living, about half the respondents reported that they no longer benefit from the project. Smallholders objected to the top-down nature of project management, and blamed political leaders for giving them something that they did not want. Discussions were also raised the conflict between livestock and crop production. Some suggestions were offered to address the conflict, but clearly this is an ongoing problem.

When asked about irrigation technology, commercial plot-holders remarked on water quality problems and pumping costs, and complained about unsuitable equipment. Commercial smallholders are willing to pay for water as long as it is affordable. General consensus existed that both foodplots and commercial units were too small and that farmers needed more training, specifically with regard to the production of irrigated crops, simple financial management, and a variety of mechanical skills. Smallholders identified the following priorities for project rehabilitation (Bembridge, 2000):

- resume electricity subsidy, so that water can be reconnected
- fence crop land to keep out livestock
- bring back the central estate (and management)
- resume mechanisation services
- make credit (free inputs) available to foodplot holders
- overcome the (perceived) salinity problem
- change existing sprinkler systems to draglines

The priority list focuses on reclaiming the rents enjoyed from the project, but also mentions relevant technology, both with respect to irrigation technology and finding a workable compromise between crop and livestock production. It is significant that farmers want the same credit services for foodplot holders that are enjoyed by commercial smallholders. It indicates that farmers consider the two groups to have the same production objectives and basic status. Moreover, the list does not mention land size per se, suggesting that land is not a binding constraint in crop production. Instead salinity problems are mentioned, presumably by farmers who rely on water pumped from the Great Fish River when it is not in flood.

There are at least two possible reasons why salinity is identified as a priority problem on the scheme. The most obvious of the two is that salinity really constrains yields, and that it is to a large extent responsible for the poor yields achieved by small-scale irrigators. This is not likely given the salinity tolerance classification of the crops produced, which are listed as "moderately sensitive" (Department of Water Affairs and Forestry, 1993). Alternatively, raising salinity could be the community's way of requesting that all plotholders be treated equally in terms of water supply. It is then not so much that those who receive water by pipeline from Glen Melville have better quality water, but that the pipeline is a more secure and cheaper source.

Based on the resource reality and perceived problems in Tyefu, as well as extensive other experience of small-scale production in Southern Africa, Bembridge (2000) concludes that there is more to irrigation project success than getting the resources right. He also calls for getting the incentives right, echoing DeLange and Crosby (1995) who argue that the real test of project success in sustained participation. Clearly the Tyefu irrigation project failed the latter test.

While a suitable resource base and appropriate technology and institutions are necessary conditions for success, they do not ensure sustained participation. The sufficient condition is human development. "[Human development] cannot be planned; it can only be stimulated" (Bembridge, 1986). The implication is that the target community must be at the centre of all discussions about the project (Vaughan, 1997). If participation is approached as a mutual learning experience, farmers will be doing things that make sense given their experience, culture and resource reality. Only then can they effectively organise to take responsibility for settling their own differences and making their own hard allocation decisions.

Table 7.2: Sources of cash income for households on the Tyefu irrigation project

	Tyefu		Six tribal schemes	
Income category	R/year/ household	% of annual	R/year/ household	% of annual
Foodplot	183	4%	635	11%
Other business & wages	1, 680	34%	1, 982	35%
Remittances	72	1%	73	1%
Rentals & in-kind payment	8	0%	48	1%
Pensions	3, 000	61%	2, 980	52%
Total cash income	4, 943		5, 718	

Source: Van Averbeke et al, 1998

Table 7.2 shows that produce sales contribute a mere 4 percent of annual household income in Tyefu, compared to 11 percent for similar households where irrigation projects function. It could be argued - based on table 7.2 - that Tyefu households are poorer on average because they do not have access to cheap irrigation water. It would be equally valid to suggest that Tyefu households are poorer than their counterparts, because they do not have access to the basket of conditions that makes production feasible, and that cheap water per se would not solve the problem.

7.3. Efficiency analysis

The economic analysis is hampered by a lack of data. This section relies mostly on Van Averbeke et al (1998), confirming assumptions from Bembridge (2000) were possible. Both used farmer recall to collect data. Van Averbeke et al (1998) note that financial records or budgets could not even be obtained for the central estate, and that it is therefore hopeless to expect smallholders to keep records.
The analysis proceeds in three steps, starting with a gross margin analysis that does not account for irrigation costs. Irrigation costs, of which all except depreciation is out-of-pocket, are introduced in the second step. Finally a margin above labour costs is calculated. The section closes with an estimate of Tyefu's employment potential.

7.3.1. Gross margin

The small contribution of produce sales suggests that if production takes place at all, it must be used for home-consumption. Both are relevant when calculating the value of crops (Gittinger, 1982). Van Averbeke et al (1998) confirm that foodplot holders consume 56 percent of their output. The average household uses three crops in significant quantities, namely maize (363 kg/year), potatoes (241 kg/year) and cabbage (197 kg/year). Bembridge (2002) reports that prior to 1995 foodplot holders grew two-thirds of their annual maize requirement of about 1 000 kg/year, while commercial smallholders were practically self-sufficient in maize, having to buy only 40kg /year.

In 1995 annual income of commercial plot-holders was R9 290 and foodplot holders made an average of R746 from crops (Bembridge, 2000). It is not clear if Bembridge's estimates include home consumption. Van Averbeke et al (1998) do not include home consumption, reporting cash produce sales of R183 per plot in 1998, and R557 when the project was still functioning. The gross margin analysis in table 7.3 reflects Van Averbeke et al's 1995 yield assumptions and the current average plot size of 0.1882ha. Given the average plot size of 0.1882ha and the fact that the two groups grow the same crops, no further distinction is made between commercial smallholder and foodplot holders.

The gross margin analysis includes the three most important smallholder crops. Total yield per plot is calculated from quantities consumed and percentages consumed per crop, which are reported by Van Averbeke et al (1998). Cabbage is the most important crop for smallholders, who grow an average of 1 721 kg/plot, together with roughly half a ton of maize and potatoes each.

The calculated yields convert to 4.1 ton/ha for maize, 31.5 ton/ha for cabbage, 9.2 ton/ha for potatoes, which are about half of acceptable commercial yield. See chapter 5 for assumptions on commercial yields in the Lower Fish area. The estimates in table 7.3 also assume a land use intensity of 115 percent and a crop mix of 50.4 percent maize, 28.6 percent cabbage and 18.5 percent potatoes. Comparing smallholder prices to commercial prices will reveal that smallholders only get about two-thirds of commercial prices. Bembridge (2000) does not agree, arguing that the price of green mealies (corn on the cob) is about twice as high as the price of grain in the formal market. However, if the entire maize crop were valued at the higher price, the resulting cash sales would be much higher than sales recorded by Van Averbeek et al (1998).

Table 7.3: Gross margin analysis for smallholders at Tyefu in 1999 Rand

Item	Maize	Cabbage	Potatoes
Yield			
* Home-consumed production	363 kg	241 kg	197 kg
* % of produce home-consumed	81%	14%	45%
Yield / plot (0.19ha)	448 kg	1,721 kg	438 kg
Average price	R528/ton	R290/ton	R429/ton
* Value of cash sales	R44.96	R429.92	R103.29
Value of total production/plot	R236.62	R499.90	R187.81
Direct expenses			
Seed and seedlings	306	2, 200	1, 045
Fertiliser	789	1, 754	1, 334
Machine costs	235	235	235
Pesticides	336	996	1, 730
Packaging		83	69
* Out-of-pocket costs (R/ha)	R1, 666	R5, 268	R4, 413
Out-of-pocket costs/plot	R181.72	R326.08	R176.69
Gross margin/plot	R54.89	R173.82	R11.12

Source: Adapted from Van Averbeke et al, 1998 (* quoted in Van Averbeke)

Out-of-pocket expenses for the three main crops are reported on a per hectare basis by Van Averbeke et al (1998). To convert to plot level expenditure, average plot size was multiplied by 115 percent land use intensity to get effective area planted. The area planted to a particular crop is effective area planted multiplied by the crop mix share of that crop. Per hectare costs are then scaled down to the actual area per crop. For maize the calculation is as follows:

average plot size	0.1882ha
land use intensity	115%
effective land planted	0.2164ha
maize in crop mix	50.4%
area maize (ha)	0.1091ha
maize expense/plot	R181.73/plot

Out-of-pocket expenses per crop are indicated in table 7.3. It is almost twice as expensive to grow cabbage than to grow maize or potatoes. Fertiliser is an important cost item for all crops. Seed and seedlings, and pest control are important for cabbage and potatoes, but not for maize. Since maize is mostly grown for home consumption is makes sense that no packaging is required.

Despite the higher production costs, cabbage generates a substantially higher gross margin than the other two crops. Plot-level gross margin for maize is R55/plot and for potatoes is R11/plot, and for cabbage is R174/plot. Total plot gross margin is R239.82/plot, which is equivalent to R1, 274.30 /ha. If the entire scheme was converted into 0.1882ha plots, total gross margin would be R820 649/year, and the total value of cash sales would be R1 978 435/year.

7.3.2. Irrigation costs

Total gross margin is an upper limit of willingness to pay for scheme services such irrigation. This section subtracts irrigation costs to isolate a smallholder value of irrigation water that can be compared directly to estimates of commercial value presented in Chapter 6.

Irrigation costs include a maintenance fee for sprinkler equipment assuming a 15-year replacement cycle and pumping cost taken from Bembridge (2000) and includes the standard government water tariff for the Lower Fish Government Water |Scheme. In all cases per hectare values were converted to plot equivalents by multiplying by the average plot size of 0.1882ha. Total irrigation costs amount to R386.37/plot.

Table 7.4: Margin above irrigation cost for smallholders at Tyefu in 1999 Rand

	R/plot	R/ha
Gross margin	239.82	1 274.30
Water tariff	155.51	826.32
Pumping cost	197.61	1 050.00
Depreciation (15 year)	33.25	176.67
Total irrigation costs	386.37	2052.99
Margin above irrigation costs	-146.55	-778.69

It is clear from table 7.4 that the value of water to smallholders is negative, which means that in the face of scarcity it is not economically efficient to allocate water to this class of user. The margin above irrigation cost is –R146.55/plot, or –R778.69/ha for small-scale production. The total value of water in the Fish-Sundays scheme is reduced by just over R500 000/year if water is allocated for 644ha of smallholder irrigation.

7.3.3. Accounting for labour

Chapter 6 isolates commercial irrigation values by accounting for all fixed resources, defining the value of water as the unclaimed residual. It was already demonstrated that direct water costs claim the entire residual generated by small-scale crop production, and that smallholder irrigation is not an economically efficient use of water. However, this section calculates the margin above labour cost, which is the most important fixed factor in smallholder production.

Van Averbeke et al (1998) provides a detailed analysis of labour input, estimating that smallholders invest 216 man-days/year and hire and additional 1.02 days of casual labour at a wage of R12.36/day. Out-of-pocket labour expense for smallholders is a trivial R12.61/year, which does not affect the analysis in table 4.7 in any meaningful way. In contrast 216 days of family labour at an opportunity cost of R12.36/day amounts to R2 670/year for a plot, or R14 186/ha and more than R9 million for Tyefu as a whole.

A labour cost of R14 000/ha cannot be justified except for high value horticultural crops, so one has to carefully question the labour assumptions. Either 216 days grossly overestimates family labour input, or the opportunity cost of family labour is significantly lower than R12.36/day, or both. The wage rate is not completely out of line with commercial wages but probably does not apply to all family labour used in small-scale production. In fact, Bembridge's (2000) reports a per-hectare labour input of only 37.75 man-days, of which 25 percent is hired as wage labour. At the going wage rate of R12.36/day Bembridge's total labour input amounts to R467/ha, which leads to a much more reasonable estimate of just over R300 000 for Tyefu as a whole.

If family labour is not scarce, it has zero opportunity cost. Producer theory is clear that more labour will be applied where it has zero opportunity cost than if there is a positive price associated with the resource. So, neither the wage rate at which labour is valued, nor Van Averbeke et al's 1998 estimate of family labour used is unreasonable, but it is unreasonable to calculate total labour cost by combining these numbers.

This begs the question of how much employment the Tyefu project reality generates. Since there is no residual left to compensate family labour, only hired labour can be counted towards employment creation. Van Averbeke et al (1998), at a hired labour input of 5.4 man-days/ha provides the lower bound on employment and Bembridge (2000), at an estimated 9.4 man-days/ha, represent the upper limit. Total employment generated on the Tyefu scheme ranges between 13 and 23 fulltime jobs.

This section refuted the small-scale efficiency hypothesis. Binswanger and Elgin (1990) argue that small-scale traditional farmers are more efficient resource users than their commercial counterparts and equity considerations do not have to enter into the allocation debate. It is clear that in the Tyefu case one has to return to equity considerations, and the next section reviews the American Indian experience for lessons that extend to resource use in traditional communities in South Africa.

7.4. Non-efficiency arguments for allocation

Irrigation development in the American West started off with the establishment of the Bureau of Reclamation in 1902. The Reclamation Act established a fund, through the sale of public lands, from which loans were made to irrigation farmers. Despite original intentions to recover capital with interest, farmers were unable to repay their loans. The Act was subsequently changed to allow deferred payments and zero interest rates over a fifty-year period. Payments were based on ability to pay, and project feasibility required costs to be equal to benefits. Evidence shows that farmers repaid about 20 percent of the allocated cost of water (Burness et al, 1982; Cummings and Nercissiantz, 1992). Mallawaarachchi et al (1992) report that general taxes funded irrigation development in Australia as well and Vaughan (1997) reminds us that irrigation development in South Africa followed a similar route. In the light of history it is not fair to restrict the evaluation of irrigation projects for Indian tribes or traditional South African communities to efficiency analyses alone.

As Indian tribes started exercising their rights in the early 1980's it spawned a whole literature documenting this history, which may prove helpful in answering the question of what kind of access society owes to small-scale traditional irrigators in the Great Fish River basin.

The Indian rights doctrine, or Winters doctrine, is derived from *Winters vs. United States* when the Supreme Court first recognised a reserved water right for Indians. Merrill (1980) explains:

> "The Winters doctrine began when the United States sued several non-Indian settlers living on former Indian lands along the Milk River in Montana. By diverting large quantities of water, upstream settlers left insufficient water in the river to satisfy the needs of an Indian irrigation project constructed downstream by the United States on the Fort Belknap Reservation. The government's suit, in seeking to enjoin these non-Indian diversions, argued the agreement establishing the Indian reservation implicitly had reserved irrigation water for the Indians."

The court held that if land was reserved for the Indian tribes, water was reserved by implication. In practice it came to mean that "Indian reservations had a reserved right to water ... in sufficient amounts to satisfy all present and future needs of the Indians" (Burness et al, 1983). Clearly the problem with this kind of statement is that needs will be growing in the future, and that Indian rights have the possibility of replacing all existing uses. As a result the exact nature of a Winters right has been widely debated.

Commentators disagree on three main points. First, the context of Winters was agricultural use, and that raises the question of whether tribal rights are restricted to irrigation, or should be extended to the full spectrum of water uses. Secondly, according to the Winters doctrine Indian rights are reserved, which in the American setting means that it cannot be lost through non-use, and that it is by implication removed from the market. The question is if tribal water rights should be reserved, or not. The third point of debate is how the right is quantified, especially when comparing Indian projects to projects for commercial agriculture.

Opinions on how far water rights should extent differ from a full range of uses and absolute seniority to restricted agricultural use. The most radical opinion is that Indian water rights is an aboriginal right, based on the premise "first in time, first in right" (Merrill, 1980). In this spirit Indian tribes started to claim, for example "... that the Northern Cheyenne Tribe is entitled and now has and at all times had, the first, paramount and aboriginal right to the use of all waters..."(Merrill, 1980). In this one-sided declaration the tribe claims its right to all streams that rise on the Reservation and extends water use beyond domestic use and irrigation to the full range of modern uses, including manufacturing and instream flows for environmental and recreation purposes.

The implication this interpretation of traditional rights is clear. Traditional communities ought to control the significant wealth associated with water in an arid environment. Thus many authors, including Merrill (1980), ask for some qualification of traditional water rights. He argues that it is appropriate to restrict water rights to irrigation, where a traditional community has a history of irrigation. Brookshire et al (1983) and Burness et al (1983) also support an irrigation basis for quantifying Indian rights. Moore (1989) holds that an agricultural basis for quantification is not appropriate given the falling share of agricultural output in the economy. Moreover, a commitment to allocative efficiency, even within a traditional community, calls for the freedom to put the resource to its best possible use.

The second point of dispute is that Indian rights are immune to the use-it-or-loose-it condition that continuously reconfirms beneficial use under the prior appropriation doctrine that governs water allocation in the American West. Some believe that it is appropriate to reserve water for groups who cannot compete on efficiency grounds, but reserving water effectively removes the resource from the market. If a traditional community cannot sell a water right, the opportunity cost of the right is zero, so that it will not be used efficiently. Moore (1989) makes a subtle further point, namely, that as long as society fails to effectively address traditional claims, property rights are not fully specified. Potential claims from tribal users represent a threat to that prevents the market from function properly.

This raises the third point, about a fair system of quantification. The original intention of the Winters doctrine was to reserve sufficient water to "make each reservation livable" (Brookshire et al, 1983). While nobody disputes the fairness of this statement, it does not guarantee smooth implementation. See Brookshire et al (1980), Burness et al (1983) and Moore (1989). Two ideas emerge: First, be sensitive to existing users when reallocating rights to traditional communities, and secondly, make sure that the rules are the same for traditional and commercial users alike.

Moore (1989) goes as far as claiming that any quantification instrument, especially irrigable area, is "a fiction", and contrary to the spirit of the Winters doctrine. He states that fairness is not called for on affirmative action grounds, or to achieve a certain minimum per capita income, but because that was the historical rules of the game. Moore's argument raises the third point in this quantification debate, namely who is supposed to pay. Again, consensus does not exist, but many are in favour of funding the development of further irrigation projects for traditional communities from general taxes.

To conclude, the experience with Indian water rights reveals some valuable lessons for South Africa. First, the outcome of any system of quantification is only as good as the assumptions on which the results rely. Those assumptions do no – through the nature of the cost-benefit process – ensure fairness. Instead, equity, or a fair allocation, has to be decided in court. Finally, the claims of tribal groups have to be addressed before the market can function properly.

7.5. Conclusions on small-scale traditional irrigation in South Africa

Both the South African and American Indian experiences provide several important lessons for improving access for formerly disadvantaged communities.

Lesson 1: Do not answer the question of feasibility on efficiency grounds alone

This lesson needs no elaboration, but is bears repetition. If society is committed to making the scarce water resource go as far as possible, it must address the equity issue. Ignoring claims of fairness weakens the property rights on which allocative efficiency relies.

Lesson number 2: There is more at stake than just water

Awarding a water right does not mean that the right itself ensures development. Everybody who studies smallholder irrigation projects in traditional communities agrees on the crucial need for sufficient support services. Emerging farmers need more than just water; they need a package of services delivered to the farm gate.

Lesson 3: Do not presume to know

Instead of asking about the appropriate input package, it is more important to ask how relevant farming is as a means of providing rural livelihoods. If the community selects an irrigation project as the best way to improve their welfare, pick appropriate crops and technology. When left to their own devices, Tyefu farmers chose to grow maize, cabbage and potatoes, crops that are familiar in diet and easy to grow.

Experience has show again and again that planners should work with communities, and within the constraints perceived by those communities. Crops like citrus, or sugar beets, or even baby carrots for processing can all be grown with management support, but often these crops are discontinued as soon as management steps back, indicating that they were never appropriate to start with.

Lesson 4: There are always trade-offs involved

The American Indian experience has shown the importance of aboriginal rights, but also that tribal rights cannot be exercised in isolation of other uses. Economic theory offers no suggestions for awarding rights, but argue that once rights are defined, rights holders should not be locked into present use patterns. Instead, an institutional framework that allows exchange will make society better off.

Lesson 5: Wrapping a project in an Indian blanket

It does not do formerly disadvantaged communities any favour to ignore the competing claims of current water uses. However, the Indian experience has shown that there are many opportunities to "wrap a new project in an Indian blanket", that is, to align the objectives of traditional and commercial users in order to secure funding that would otherwise not be available.

CHAPTER 8: SUMMARY AND CONCLUSIONS

8.1. Introduction

Chapter 8 presents a policy evaluation for the Fish-Sundays scheme. The two foremost policy questions concern financial feasibility and efficient allocation of water. Step 4 of the analysis calls for a comparison of total benefits to costs to estimate the Fish-Sundays scheme's financial feasibility, while step 5 examines the opportunity cost of intra-regional reallocation, inter-regional reallocation and reallocation between irrigation and other stakeholders. The remainder of Chapter 8 offers conclusions about the policy framework and lists topics for further investigation.

8.2. Total value of current use

A benefit-cost ratio compares total value to costs. Two benefit measures are presented, namely tariff income and the total value of irrigation reported in table 6.13. Commercial irrigators pay a water fee charged as a flat rate per hectare, while municipal water is priced volumetrically. The fees represent the Department of Water Affairs and Forestry's income, but are a cost to users of water. From a social perspective value is defined as aggregate residual profits generated by irrigation farming. In both cases costs are defined as operation and maintenance costs. All values are in 1999 Rand.

In 1999 the Department of Water Affairs and Forestry collected R11.2 million in water fees and operations and maintenance costs were R10.74 million, indicating that all variable costs are covered. Return on investment is not accounted for. A new pricing strategy has been proposed in terms of the National Water Act (Act 36 of 1998) whereby the Department of Water Affairs and Forestry intends to recover full water resource development costs on an increasing block rate scheme (Department of Water Affairs and Forestry, 1999). It is clear that tariffs will have to rise significantly in order to cover any non-trivial capital expenditure.

Total benefit is estimated to be R26 940 450 in 1999 Rand while variable cost for the same period was R10 174 000. The benefit-cost ratio is 2.65 and is still positive even if the simulation model overestimates irrigation values by half. The maximum sustainable capital charge for the scheme is R16 766 000. If levied on the commercial irrigation requirement of 582 million m^3/year, the average increase will be R0.029/m^3.

Aside from whether full cost recovery is desirable or not, it is clear that commercial irrigators derived a profit from water in 1999. This raises the question of whether this profit should be interpreted as a subsidy paid by society to this group of stakeholders. The investment that generated the profit derived from water use is a subsidy from the general taxpayer to irrigators, but not all profits can be extracted through tariffs. Theory shows the marginal producer to be indifferent between irrigating and not irrigating, and that this hypothetical individual will cycle in and out of production in the long run in response to relative price changes. In reality in the short run, farmers command very different resource mixes and do not adjust instantaneously to changing prices. Hence a low cost farmer, who farms for example fertile land or is a good manager, will still make a profit at a particular water fee while his neighbour will go out of business. It is clearly not possible to extract all resource rents from users of any resource due to dissimilar resources.

8.3. Opportunities for reallocation

Table 8.1 lists marginal irrigation values at the current allocation and figure 8.1 shows opportunities for redistributing water. Given the uncertainty about risk aversion coefficients, it is more meaningful to examine directions of reallocation than specific values. Shadow prices range between zero and R0.2115/m^3.

Table 8.1: Marginal water values for the Fish-Sundays at current allocation

		Water rental		Purchase price	
Representative farm		R/m3	R/ha	R/m3	R/ha
Type 1	UF irrigator	0.0011	15	0.02	297
Type 2	UF stockman	0.0067	90	0.13	1,809
Type 3	UF farm business	0.0106	143	0.21	2,862
Type 4	UF dairyman	0.0412	556	0.82	11,124
Type 5	MF irrigator	0.0003	4	0.01	81
Type 6	MF stockman	-	-	-	-
Type 7	MF farm business	0.0120	162	0.24	3,240
Type 8	MF dairyman	0.0427	576	0.85	11,529
Type 9	LF irrigator	-	-	-	-
Type 10	LF stockman	0.0014	18	0.03	350
Type 11	LF farm business	0.0163	204	0.33	4,075
Type 12	LF dairyman	0.0378	473	0.76	9,450
Type 13	Small mixed	0.1702	1,532	3.40	30,636
Type 14	Large stable citrus	0.2115	1,904	4.23	38,070
Type 15	Small growing citrus	0.0815	734	1.63	14,670
Type 16	Large growing citrus	-	-	-	-

There are minor differences in water value for a given farm type across the Upper, Middle and Lower Fish regions, but noticeable differences exist among farm types within a region. Irrigators and stock farms consistently record low water values, while farm businesses value the marginal unit of water at between R150/ha and R200/ha. Dairy farms derive more than three times more than farm businesses from the marginal unit of water. The greatest amount of variability is found in the Sundays area where marginal water values range between zero and R1 904/ha/year. Capitalised at 5 percent the maximum associated purchase price is just over R38 000/ha. A mature citrus orchard sold for R60 000/ha in 1999 and replacing an orchard is assumed to have cost R28 000/ha in 1999.

Two conclusions emerge from table 8.1. Firstly, the hypothesis that Sundays River citrus producers are able to bid water away from fodder crop producers in the Fish River region is supported by the simulation results. Secondly, there is very little evidence to suggest reallocation from the Upper to the Middle or Lower Fish. On the contrary, the simulation results indicate that water will migrate upstream.

The policy scenarios examined in the remainder of this section depart from the marginal values listed in table 8.1, as well as the capacity constraints reported in figure 8.1. In all cases the opportunity cost to commercial agriculture is interpreted as the minimum benefit derived from use in the non-irrigation sectors. Table 8.2 lists irrigation opportunity costs for incremental units of water in the Fish River. On efficiency grounds alone the Fish region will release 60 percent of the current allocation to irrigation before any water is released from the Sundays River.

8.3.1. Among classes of irrigators

Transfers from one farmer to his neighbour on the same canal invoke no capacity constraints in most cases. Canal capacity will be binding if all use is transferred to the lower end of the canal. However, there is usually some relationship between irrigable land and canal capacity, so that one can safely assume that capacity constraints will not apply. Transfers between ditches within the same area are more controversial. It is possible that the application to transfer water from ditch A to ditch B is refused on the grounds of insufficient capacity. However, land serviced by different ditches within the same region is suitable for the same range of crops so that farmers should be indifferent between land serviced by ditch A or ditch B.

In the Upper, Middle and Lower Fish farm businesses and perhaps dairymen will buy water from stock farmers and irrigators. This result is intuitive and the hectare equivalent rental values and even purchase prices are of the same scale as current water tariffs and land prices for the area. If the entire Upper Fish is converted to farm businesses, total water value increases from R1.25 million/year to R1.78 million/year, or 43 percent. A similar calculation for the Middle Fish reveals that if all land is converted to dairy farms total water value increases by 66 percent to R4.51 million. If the more likely scenario of converting all land to farm businesses occurs, total irrigation value increases by 87 percent, or R2.37 million/year in 1999 Rand. Reallocating water from inefficient to efficient producers in the Lower Fish yield similar results. Reallocating all water to farm business will total regional water value from R7.85 million/year to R13.51 million/ year. If, on the other hand, if all land is converted to dairy farming which recorded the highest marginal value of all Lower Fish farms, total value falls by 9 percent compared to the current allocation. Finally, if all land in the Sundays River is converted to large stable citrus farms total water value for the region doubles from R14 million to R27 million.

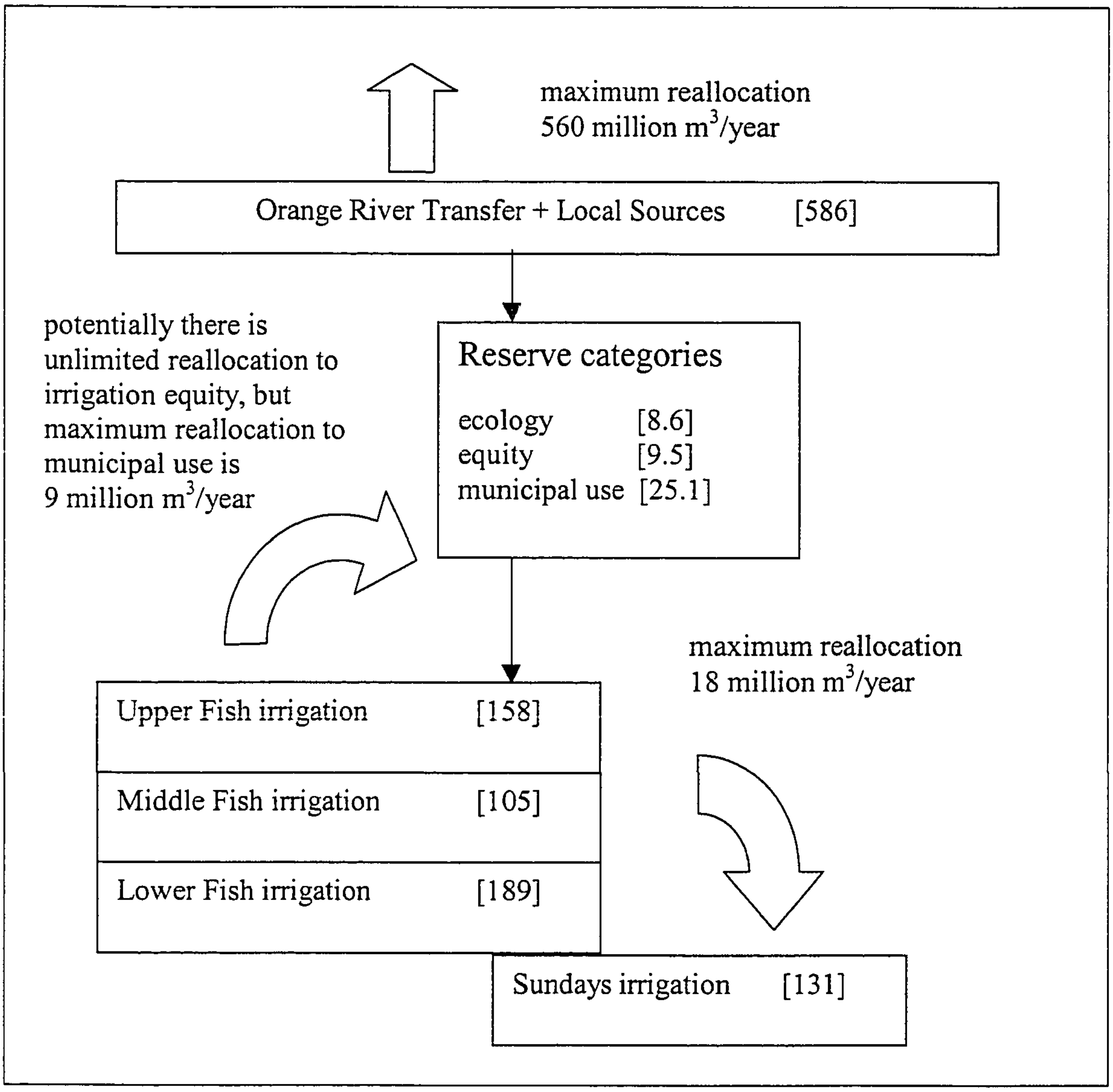


Figure 8.1: Current allocation and maximum reallocation in million m^3/year for the Fish-Sundays scheme

8.3.2. Between regions

Each region provides unique production opportunities, so that entire classes of irrigators may migrate if infrastructure permits. There is no limit to downstream reallocation from the Upper to the Middle Fish, or the Middle to the Lower Fish since water can be abstracted directly from the river in most cases. The only limiting constraint to inter-regional irrigation transfers is an infrastructure constraint in the Sundays limiting transfers to 18 million m^3/year.

Table 8.3: Gains from reallocating water to the Sundays in 1999 Rand

Price R/m3	Quantity Farm m3	Quantity Region mil m3	Cumulative quantity mil m3	Regional value Rand 1999	Farm type	
0.28622	71,656	5.88	5.88	1,682,944	15	15
0.15253	43,409	4.82	10.70	1,632,092	13	13
0.06481	71,656	5.88	16.58	1,074,550	15	15
0.04353	506,688	9.12	25.70	1,118,618	16	16
0.03517	423,874	13.99	39.69	1,395,818	14	14
Total		39.69		6,904,023		

Table 8.3 calculates the gain from reallocating almost 40 million m^3/year from the Great Fish River basin to the Sundays River basin to be about R7 million. If constrained to the existing infrastructure capacity total value will increase to about R4.4 million if water is allowed to migrate to the Sundays River basin. Table 8.2 indicates that 77 million m^3/year can be transferred from the Fish to the Sundays areas at zero opportunity cost to commercial irrigation.

8.3.3. From irrigation to competing uses

The reserve classes comprise municipal use, environmental use, and water allocated to small-scale irrigation in order to redress past racial discrimination. Municipal use is the only category to which an existing capacity constraint applies. Port Elizabeth's connection to the Fish-Sundays scheme has a capacity of 20 million m^3/year. Historically the city used 11.4 million m^3/year and. paid a fee of R0.32/m^3 for water from the Fish-Sundays scheme. The next cheapest source costs R0.86/m^3. Port Elizabeth therefore would prefer to use the Fish-Sundays scheme up to the existing capacity constraint. Reallocation to the existing capacity constraint on municipal water can be met at a zero opportunity cost to commercial irrigation.

Table 8.2: Shadow price of irrigation water in the Fish-Sundays in 1999 Rand

	Quantity available at each price				
Price R/m3	Fish Increment mil m3	Fish Cumulative mil m3	% of irrigation	Sundays Incr. mil m3	% of irrigation
0.0352	0.00	349.71	60%	33.26	6%
0.0352	0.00	349.71	60%		
0.0290	1.04	349.71	60%		
0.0290	0.00	348.67	60%		
0.0251	1.14	348.67	60%		
0.0251	0.00	347.53	60%		
0.0223	0.55	347.53	60%		
0.0223	0.00	346.99	60%		
0.0203	1.72	346.99	60%		
0.0203	0.00	345.27	59%		
0.0168	0.00	345.27	59%		
0.0163	55.44	345.27	59%		
0.0163	0.00	289.83	50%		
0.0120	24.83	289.83	50%		
0.0120	0.00	265.00	46%		
0.0111	18.52	265.00	46%		
0.0111	0.00	246.48	42%		
0.0101	0.00	246.48	42%		
0.0101	0.00	246.48	42%		
0.0082	4.97	246.48	42%		
0.0082	0.00	241.51	41%		
0.0080	2.75	241.51	41%		
0.0080	0.00	238.75	41%		
0.0067	42.30	238.75	41%		
0.0067	0.00	196.45	34%		
0.0054	3.22	196.45	34%		
0.0054	0.00	193.23	33%		
0.0045	0.67	193.23	33%		
0.0045	0.00	192.56	33%		
0.0039	17.01	192.56	33%		
0.0039	0.00	175.55	30%		
0.0032	0.33	175.55	30%		
0.0032	0.00	175.22	30%		
0.0030	4.32	175.22	30%		
0.0030	0.00	170.90	29%		
0.0018	22.98	170.90	29%		
0.0018	4.46	147.92	25%		
0.0018	0.00	143.46	25%		
0.0015	32.59	143.46	25%		
0.0015	0.00	110.87	19%		
0.0014	4.04	110.87	19%		
0.0014	0.00	106.83	18%		
0.0011	29.20	106.83	18%		
0.0011	0.00	77.63	13%		
0	77.63	77.63	13%		
0					

Furthermore, table 8.2 clearly indicates that opportunity cost of commercial irrigation for the first 77 million m^3/year is zero. The implication is that current projections of the joint environmental and equity requirement can be satisfied three times over without any opportunity cost to irrigation.

8.3.4. Changing the magnitude of the inter-basin transfer

The maximum volume delivered by the tunnel was 650 million m^3 supplied in the 1997/98 season. Given Basson's 1999 proposal for the Orange River basin it is unlikely that the transfer volume will be increased. Thus, the capacity constraint on the tunnel is irrelevant.

The salinity externality is more important. As stated before, the environmental reserve is assumed to internalise all water quality externalities. However, the precise nature of the irrigation-salinity externality when transfer volumes are scaled down significantly has not been studied to date. At the moment the water quality requirement is about 1.5 percent of the annual transfer volume, but it is not known how the environmental requirement will change if the transfer volume is reduced. A smaller transfer volume suggests smaller irrigated areas at the current systems efficiency, or the same area irrigated more efficiently, or a combination of the two. Under either scenario the total return flow will be reduced, leading to smaller amounts of salts leached to the river, which in turn implies better water quality. The environmental requirement may therefore decrease proportional to the transfer volume if the inter-basin transfer is scaled down.

The opportunity cost of diverting water from existing uses, including the Fish-Sundays scheme, is the cost of expanding storage in the Orange River system. Limited additional capacity of 315 million m^3/year at an average annual cost of R0.05/m^3 can be created in the Orange River basin (Basson, 1999). The unit cost of supply and the decision not to reduce the transfer to the Fish-Sundays scheme implies that the average value of water in the Fish-Sundays scheme is assumed to be more than R0.05/m^3. The average simulated value of water for the current distribution is R0.046/m^3/year and if efficient reallocation takes place within irrigation, the value increases to R0.082/m^3/year. A second stage of development on the Orange River will add 850 million m^3/year at an average annual cost of R1.27/m^3. While Basson (1999) was adamant that water will not be reallocated from the Fish-Sundays scheme even at this unit cost, the results of this study indicates that the Fish-Sundays scheme is a possible source of cheap water that should be investigated further.

Table 8.4 reports cumulative opportunity cost to commercial irrigation of reducing the inter-basin transfer. The opportunity cost of cumulative quantities does not account for transfers to competing uses. Simulation results show that the transfer can be reduced by 14 percent at a zero opportunity cost to commercial irrigation, and that a by a third at the opportunity cost of R214 736/year in 1999 Rand. Marginal willingness to pay is

R0.0045/m^3 at this constraint level. Transfers is reduced by more than two thirds at a shadow price of R0.0389 and the total opportunity cost to commercial irrigation of this reallocation is estimated to be R3.27 million in 1999 Rand.

Table 8.4 fulfils the objective of the study by shadow pricing existing irrigation. The result is a valuable point of departure for further specific policy analyses regarding society's equity objectives. However, the result was generated by a model that made a number of simplifying assumptions that require further investigation.

Table 8.4: Cumulative opportunity cost to irrigation of reducing the transfer

Unit price R/m3	Cumulative Value Rand	Cumulative Quantity mil m3
0.0000	-	77.63
0.0011	31,523	106.83
0.0014	37,134	110.87
0.0015	85,959	143.46
0.0018	93,889	147.92
0.0030	134,774	170.90
0.0032	147,809	175.22
0.0039	148,845	175.55
0.0045	214,736	192.56
0.0054	217,785	193.23
0.0067	235,287	196.45
0.0080	520,180	238.75
0.0082	542,122	241.51
0.0101	582,806	246.48
0.0111	582,806	246.48
0.0120	788,161	265.00
0.0163	1,084,905	289.83
0.0168	1,990,603	345.27
0.0203	2,025,479	346.99
0.0223	2,037,630	347.53
0.0251	2,066,178	348.67
0.0290	2,096,386	349.71
0.0352	3,266,278	382.97
0.0389	3,270,675	383.09

8.4. Further investigation

The present model has several weaknesses including modelling risk as a residual, using only a single crop-water combination for each irrigation technology and by ignoring salinity and drainage. Further investigation of these three aspects will improve the accuracy of irrigation shadow prices, but will still not be a direct estimate of non-irrigation benefits, which represents the final main requirement for further investigation.

MOTAD models risk as a residual category, which in the Ricardian rents framework reduces the value of water. While a Von Neuman-Morgernstern frontier relating variation in income to utility of income is implicit to figure 6.2, no attempt has been made to survey irrigators for their actual risk preference. Instead the linear programming model was calibrated to observed enterprise mixes. The model can be improved by including data on local risk preferences.

A second way in which the irrigation model can be improved is to include specific data about the underlying crop-water function, and the actual irrigation practices that farmers use. Chapter 2 referred to the theoretical discussion surrounding the best fit for a crop-water function and the model abstracted from the debate by assuming a crop-specific water requirement for the area by irrigation local experts. No attempt was made to confirm the actual irrigation practices of farmers in the region and no previous irrigation studies were available on which any other assumption could be based.

The third topic for further research involves a salinity and drainage dimension for the model. The crop-water function, and specifically whether too much water harms yield or not, depends on drainage and salinity problems. At the moment the scheme's salinity is managed by allocating water to streamflow, but it may be more efficient to tax salinity direction. A policy model to test a salinity hypothesis requires a groundwater component that will in turn need detailed returnflow data.

The consumptive use versus diverted use debate places certain limits on water transfers in the American West. The consumptive use restriction has not been introduced formally into the local debate, but a variation of consumptive use has been implemented by the Department of Water Affairs and Forestry in recent water transfers in the Fish-Sundays scheme. Most historical transfers reallocated water downstream, which in the case of the Fish-Sundays means that a larger per-hectare quota is exchanged for a smaller quota. When an Upper Fish quota is sold to a Sundays farmer, he receives only a standard quota of 9 000m^3/year instead of the actual volume of 13 500m^3/year. The reason given is that the difference is claimed as evaporation and other river losses. Again, a model that can explicitly consumpted versus diverted use requires detailed data on actual irrigation practices, soil conditions and quantity and quality of returnflows from irrigation.

8.5. Conclusions

The study was successful in terms of estimating the range or marginal benefits likely to be observed in irrigated agriculture, but the models, while able to produce the right direction of response, are too crude to estimate exact water values. The experience shows, that while consistent and theoretically correct, the policy framework is not easy to implement. The first of these difficulties involve pricing irrigation water. The analysis presented here presupposes volumetric pricing of irrigation water. If water is a fixed cost to irrigators, a rational irrigator has not incentive to save water.

Volumetric prices can be administered by the Department of Water Affairs and Forestry or generated in a rental market for water, such as the one operating in Colorado described by Nieuwoudt (2000). Administered prices allow the government direct control of the reallocation process, but are by nature data intensive. Furthermore, the number of assumptions required for even a simple model leaves room for significant inaccuracies. Finally, the results for the 16 typical farms show that irrigation farms are not homogenous and that willingness and ability to pay for water may differ significantly within a small geographic area. The present study relies heavily on the methods and approaches of the water value literature in the Western Unites States, particularly on the work of Professor Robert Young and his students. While these studies are relevant to the South African contexts one must be careful not to overestimate what these models can do. It was never the intention of Young's models to provide the data for demand management, but merely to illustrate value differentials in order to argue for markets.

Linear model is all that was needed to answer the question. The non-linear relationship between utility of income and variability of income is presented as maximising profit subjects to an exogenously specified level of variation in income.

The Department of Water Affairs and Forestry intends to reduce water demand by increasing the price of water, and farmers are expected to respond by discontinuing irrigation or changing to water saving technology. One of the less well-established conclusions from the present study is that administered prices may not be the most effective way to change the relative cost of irrigation systems. The models shows that water saving can be achieved by increasing agricultural wages. Raising wages is just one example of changing the relative prices of irrigation systems. Other options worth investigating are irrigation hardware subsidies or taxing irrigation return flows.

Finally, it must be pointed out that full cost recovery is not necessarily consistent with Pareto efficiency. When a tariff is set above marginal value product, theory predicts that production will shut down, and that consumers will discontinue consumption. As a result no costs are recovered. From the government's point of view, and certainly on new projects, it is important to confirm financial sustainability, but to increase tariffs on existing schemes may put the Department of Water Affairs and Forestry in a position where it is not able to sell any water.

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APPENDICES

Appendix 3.1: Water balance for the Great Fish and Sundays Rivers

	Volume 1 000 000 m^3/year	Comments
Requirements		All requirements at a 1:50 year assurance
Irrigation	626.0	(Quota + conv. losses)×ha
Urban	15.2	
Rural (human reserve)	9.5	Population×days×25 litre
Mining	-	
Dryland sugar cane	-	
Power generation	-	
Forestry	1.7	Reduction in yield
Alien vegetation	1.5	Reduction in yield
Ecological reserve	8.6	Reduction in yield
River losses	112.0	
Transfers out	23.4	
Total requirements	797.9	
Resources		
Surface water	179.7	
Groundwater	21.9	
Returnflows: irrigation	109.4	
Returnflows: urban	6.9	
Urban runoff (paved areas)	1.9	
Transfers in	560.0	Gariep Dam
Total resources	879.8	
Yield balance	81.9	Resources – requirements

Source: Directorate Planning, Department of Water Affairs and Forestry

Appendix 4.1: Municipal water data

Year	Real Price (100=1995)	High Income Residential	Commercial	Industrial	Low Income Residential
	c/litre	million m^3/year			
1988	139.05	18.462	10.734	3.332	0.84
1989	144.05	12.251	7.414	6.455	0.779
1990	159.94	16.007	8.288	7.308	0.913
1991	151.06	9.930	6.689	6.851	0.797
1992	166.67	11.290	6.445	6.214	0.87
1993	166.46	14.280	7.456	6.093	1.118
1994	177.78	17.821	9.313	5.491	0.778
1995	180.00	18.680	9.54	7.004	1.134
1996	165.39	18.729	9.695	6.098	1.345
1997	174.26	20.478	9.865	5.567	1.272

Source: City Engineer's office, Nelson Mandela Metropolitan Municipality

Appendix 5.1: Farmer Surveys

FARMER SURVEY: GREAT FISH RIVER
Project K5/987 of WRC
Economic value of water in the Fish and Sundays Rivers

Lesser irrigation board(s):

Farm size: **(Include all farms managed as a single unit, including rented land.)**

veld	ha
irrigated land (currently irrigated)	ha
scheduled area	ha

Percentage of expected gross income derived from the following enterprises:

wool sheep	%
mutton sheep	%
angoras	%
other goats	%
beef cattle	%
dairy	%
lucerne (hay sales)	%
potatoes	%
dry beans	%
pumpkins	%
other (please specify)	%

Irrigation system:

flood irrigation	ha
sprinklers / draglines	ha
centre pivot	ha

Fax to 021-560 2854 or post back in the envelope provided.
Thank you

FARMER SURVEY: SUNDAYS RIVER
Project K5/987 of WRC
Economic value of water in the Fish and Sundays Rivers

Location	Addo	Sunland	Kirkwood	

Farm size: **(Include all farms managed as a single unit, including rented land.)**

scheduled hecares	ha
irrigated land (currently irrigated)	ha
land available to expand irrigation	ha

Enterprise mix	**Area planted to a given crop (ha)**	**% of expected income**
navels	ha	%
lemons	ha	%
soft fruit (clems etc.)	ha	%
valencia types	ha	%
vegetables 1.	ha	%
(please name) 2.	ha	%
3.	ha	%
lucerne (hay sales)	ha	%
dairy	cows	%
other livestock		%
other		%
Share of total gross income derived from farming		%

If farming contributes the largest share of your income, please complete the back of the survey as ell.

Fax to 021-560 2854 or post back in the envelope provided.
Thank you

Recent citrus plantings	Cultivar	Area (ha)
1997		ha
1998		ha
1999		ha
Plantings scheduled for next 2 years		ha
What is the average age of your orchards?		years

Irrigation system	
flood irrigation	ha
microjets	ha
drip (conventional)	ha
Martinez system	ha
sprinklers / draglines	ha
centre pivot	ha

How do you plan your irrigation applications?	
Irrigate according to a set program	
Use neutron probe to schedule	
Use tensiometers to schedule	
Probe or tensiometers to double check a set program	
Dig holes	
Watch trees	

Thank you

Appendix 5.2: Raw data farmer survey: Sundays

Sundays Survey data

No	Location	Sched	Irrigated	Navels	Lemon	Clems	Vals	% income derived from Other	Lucern	Dairy	Beef	Sheep	Vegs	Other	Non farm inc.	Recent citrus plantings 1997	1998	1999	Young trees	% young	%growth
1	Addo	40	28	7	0	0	0	0	0	0	0	0	93	0	1	0	0	0	0	0	-0.04
2	Kirkwd	1.5	4	12.5	0	12.5	0	0	0	0	0	0	0	75	1	0	0	0	0	0	-0.04
3	Kirkwd	95	90	22	18	15	33	12	0	0	0	0	0	0	10	0	0	0	0	0	-0.04
4	Incomplete																				
5	Kirkwd	17	17	25	0	0	75	0	0	0	0	0	0	0	1	0	0	0	0	0	-0.04
6	Sunland	9	6	10	0	0	0	0	85	0	0	0	3	2	1	0	0	0	0	0	-0.04
7	Addo	20.2	20.2	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	-0.04
8	Sunland	50	25	0	0	0	0	0	20	0	0	80	0	1	90	0	0	0	0	0	-0.04
9	Incomplete																				
10	Incomplete		household use only																		
11	Addo	61	35	0	0	0	0	0	25	75	0	0	0	0	1	0	0	0	0	0	-0.04
12	Addo	160	160	0	0	0	0	0	25	75	0	0	0	0	0	0	0	0	0	0	-0.04
13	AS	56	56	0	0	0	0	0	48	0	0	0	22	30	1	0	0	0	0	0	-0.04
14	Sunland	30	25	0	0	0	0	0	44	0	0	0	32, 12	0	0	0	0	0	0	0	-0.04
15	Addo	36	34	0	30	0	0	0	30	0	0	40	0	0	2	0	0	0	0	0	-0.04
16	Sunland	16	16	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	-0.04
17	Addo	16.2	16	0	0	0	0	0	2	87	0	8	0	3	1	0	0	0	0	0	-0.04
18	Addo	15.3	15.3	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	-0.04
19	Sunland	8.5	8.5	0	0	0	0	0	75	0	0	0	2	0	1	0	0	0	0	0	-0.04
20	Addo	25.2	25.2	0	0	0	0	0	100	0	0	0	0	0	80	0	0	0	0	0	-0.04
21	Incompl	12.5																			
22	Unspc	13.7	13.7	0	0	0	0	0	100	0	0	0	0	0	1	0	0	0	0		
23	Sunland	27	40	0	0	0	0	0	60	0	10	0	30	0	1	0	0	0	0	0.00	-0.04
24	Sunland	104	96	0	0	0	0	0	30	0	0	0	0	70	1	7.1	21.3	3.6	32	0.33	0.07
25	Kirkwd	45	35.26	0	95	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0.00	-0.04

26 Addo	181	140	18	40	17	25	0	0	0	0	0	0	0	0	10	5.5	7.5	23	0.16	0.01
27 Addo	120	150	40	9	5	30	1	15	0	0	0	0	0	0	8	8	22	38	0.25	0.04
28 Sunland	38	38	16	21	5	52	5	0	0	0	0	0	0	30	10	6	0	16	0.42	0.10
29 Sunland	25	80	3.6	27	0	49.4	0	0	0	0	0	0	0	30	22	40	0	62	0.78	0.22
30 Kirkwd	25	25	20	35	15	25	5	0	0	0	0	0	0	0	4.5	1	4	9.5	0.38	0.09
31 Addo	50	40	10	50	7	33	0	0	0	0	0	0	0	2	3.43	0.7	4	8.13	0.20	0.03
32 Kirkwd	30	30	57	6.8	11.6	24.6	0	0	0	0	0	0	0	1	2	2	2.6	6.6	0.22	0.03
33 Addo	20.8	15.7	11	33	11	33	7	0	0	0	0	0	0	80	1	2.7	1	4.7	0.30	0.06
34 Sunland	380	235	28	24	19	27	2	0	0	0	0	0	0	0	15.2	15.3	13.5	44	0.19	0.02
35 Kirkwd	15	15	44	13	0	40	1	0	0	0	0	2	0	0	0	0	0	0	0.00	-0.04
36 Kirkwd	72	55	25	10	15	25		0	0	0	25	0	0	0	8	9	9	26	0.47	0.12
37 Addo	32	23	10	55	0	20	0	15	0	0	0	0	0	25	4	3	1	8	0.35	0.08
38 Kirkwd	120	114.34	36.23	16.71	3.54	31.16	12.36	0	0	0	0	0	0	0	9.68	0	5.4	15.08	0.13	0.00
39 Kirkwd	48.5	66	19	7	6	12	6	0	0	0	0	50	0	1	6	8	7.1	21.1	0.32	0.07
40 Kirkwd	95	84	23	16	23	18	18	2	0	0	0	0	0	0	10	10	1	21	0.25	0.04
41 Addo	66	42	10	80	0.2	9.8	0	0	0	0	0	0	0	1	7	0	4	11	0.26	0.05
42 Sunland	19	10	20	20	10	50	0	0	0	0	0	0	0	1	1	1.5	1.5	4	0.40	0.09
43 Kirkwd	40	50	75	5	5	5	0	0	0	5	0	5	0	1	4	6	1	11	0.22	0.03
44 Kirkwd	32.7	32.7	18	10	0	17	5	32	0	0	0	0	0	18	3	0	0	3	0.09	-0.01
45 Kirkwd	12	12	20	10	10	10	20	0	0	30	0	0	0	40	2	2	2	6	0.50	0.13
46 Kirkwd	25	25	44	23	12	21	0	0	0	0	0	0	0	1	0	0	0	0	0.00	-0.04
47 Kirkwd	60	60	20	20	35	25	0	0	0	0	0	0	0	0	4	0	0	4	0.07	-0.02
48 Addo	25	58	6	40	0	54	0	0	0	0	0	0	0	0	25	33	0	58	1.00	0.29
49 Incompl	164	180																0		
50 Sunland	57	90	33	33	0	33	0	0	0	0	0	0	1	0	4	0	8	12	0.13	0.00
51 Addo	20	30	33	40	0	27	0	0	0	0	0	0	0	0	0	1.5	0	1.5	0.05	-0.02
52 Kirkwd	27	20	60	35	5	20	0	0	0	0	0	0	0	0	0	0	0	0	0.00	-0.04
53 Kirkwd	70	70	35	10.5	18	36	0.5	0	0	0	0	0	0	0	1.5	4.2	3.5	9.2	0.13	0.00
54 AK	250	250	30	25	20	20	5	0	0	0	0	0	0	1	50	20	10	80	0.32	0.07
55 Kirkwd	222.7	109.41	32	20	8	40	0	0	0	0	0	0	0	0	0	0	0	0	0.00	-0.04
56 Incompl	15	12																0		
57 Kirkwd	120	130	40	20	2	30	8	0	0	0	0	0	0	40	2	4	2	8	0.06	-0.02
58 Sunland	50	55	40	8	16	36	0	0	0	0	0	0	0	0	4	4.5	3.5	12	0.22	0.03
59 Sunland	42	42	10	12	8	10	0	0	0	0	0	40	20	0	6	2	0	8	0.19	0.02
60 Kirkwd	110	110	40	20	10	30	0	0	0	0	0	0	0	0	4	4	2	10	0.09	-0.01
61 Kirkwd	21	16	33	18	5	44	0	0	0	0	0	0	0	0	0	0	0	0	0.00	-0.04

62 Kirkwd	70	54	60	10	0	30	0	0	0	0	0	0	0	1	3	2	2	7	0.13	0.00
63 Kirkwd	150	94	35	22	16	25	2	0	0	0	0	0	0	0	5.21	0.74	5.42	11.37	0.12	0.00
64 Kirkwd	14.5	14.5	50	0	0	50	0	0	0	0	0	0	0	0	1	1	0	2	0.14	0.01
65 Kirkwd	8.2	8.2	60	5	15	20	0	0	0	0	0	0	0	1	0.5	0	0	0.5	0.06	-0.02
66 Sunland	58	58	38	38	3	21	0	0	0	0	0	0	0	1	0	4	3	7	0.12	0.00
67 Addo	50	50	43	25	2	30	0	0	0	0	0	0	0	1	1	1	1	3	0.06	-0.02
68 Kirkwd	40	30	23	34	13	17	13	0	0	0	0	0	0	40	0	0	2	2	0.07	-0.02
69 Kirkwd	120	115	38	13	8	37	4	0	0	0	0	0	0	0	5	5	2	12	0.10	-0.01
70 AK	160	110	15	5	10	5	5	0	0	0	0	0	60	1	0	20	20	40	0.36	0.08
71 Kirkwd	120	200	45	5	10	40	0	0	0	0	0	0	2	1	25	25	10	60	0.30	0.06
72 Addo	40	40	10	60	10	15	5	0	0	0	0	0	0	25	5	6	0	11	0.28	0.05
73 Unspc	75	52	18	28	17	37	0	0	0	0	0	0	0	1	30	0	0	30		
74 Addo	136	100	19	40	15	10	0	0	0	0	0	18	0	0	15	15	15	45	0.45	0.11
75 Addo	32	35	33	33	10	20	4	0	0	0	0	0	0	0	4	4	4	12	0.34	0.07

Appendix 5.3: Raw data farmer survey: Great Fish

			land in ha			% income derived from										Irrigation system ha			
No	Location	Loca.	Sched.	Irrigate	Veld	Wool	Mutton	Angora	B/goats	Beef	Dairy	Lucern	Maize	Other	Specify	Flood	Sprink.	Pivot	Drip
1	Marlow	M	18.9	15	0							1				15			
2	?	A	10	50	1600	0.3	0.15		0.25			0.25		0.05	Pumpkin	28	22		
3	Boschberg	L	100	100	2600		0.3	0.3		0.3		0.1				100			
4	Mortimer	M	241	52	3002	0.163	0.488	0.04				0.21	0.1			52			
5	?	A	80	80	59	0.2	0.2					0.4	0.2			80			
6	?	A	71	93	102			0.02			0.98					71	22		
7	Marlow	M	480	390	13595	0.05	0.15	0.3		0.1		0.35	0.01	0.04	Pot, wheat	390			
8	HoughamA	L	0	1.9	0	Household consumption										1.9			
9	Tarka,Scan	M	80	70	262						0.95		0.05			70			
10	Marlow	M	23	33	23		0.3					0.3		0.4	Grape/bean	23	10		
11	Teebus	U	42.5	70	0	0.1	0.3			0.1		0.1		0.4	Horserad	60	10		
12	?	A	130	130	100					0.05	0.7	0.25				130			
13	Marlow	M	9.7	9.7	0							1				9.7			
14	Scanlen	M	238	194	927		0.113	0.11	0.008	0.01		0.567	0.139	0.047	wheat, feed	194			
15	Bo-Grasrug	U	232	140	4176	0.2	0.02			0.08		0.7				140			
16	?	A	75	65	231							0.3		0.7	Horserad.	65			
17	Teebus	U	80	80	26000	0.9				0.1						80			
18	?	A	298	250	600					0.3						220			
19	Knutsford	U	248	200	400	0.05	0.05					0.1		0.8	Ostriches	200			
20	?	A	120	120	2000		0.1					0.7		0.2	Unspec	120			
21	Bo-Grasrug	U	160	160	1315		0.2			0.1		0.6	0.1			40	5	105	
22	?	A	56	50	1000		0.005				0.95			0.045	Ostriches	50			
23	?	A	760	406	19994	0.6		0.25						0.15	Ostriches	406			
24	?	A	346	220	8300	0.25	0.02			0.1		0.2	0.2	0.23	Ostriches	200	200		
25	?	A	52	45	4400	0.8				0.15		0.025		0.025	Grapes	45			
26	HoughamA	L	101	135	6000	0.2	0.04			0.14	0.46	0.06		0.1	Potatoes	135			
27	?	A	47	20	1466	0.2	0.2	0.5	0.05	0.05							20		
28	Tarka	M	60	60	200	0.3			0.04	0.04		0.4	0.2	0.02	Dry beans	60			

29	Renfield	L	430	430	4595		0.022		0.023	0.2		0.16	0.185	0.41 Potatoes	103	172	155	
30	Boschberg	L	129	129	2376	0.15	0.05	0.4		0.3		0.1			40	30	20	29
31	?	A	94	90	640		0.1			0.1	0.5	0.3			45	45		
32	?	A	70	70	10							0.875		0.125 Potatoes	70			
33	Klipfontein	L	51	51	211		0.08				0.87			0.05 Paprika	51			
34	?	A	60	50	2500		0.2	0.55				0.12	0.13		50			
35	?	A	108	80	1000					0.1		0.9			60	10	10	
36	?	A	38	92	4620		0.6			0.2		0.1		0.1 Unspec.	92			
37	?	A	69	50	4171	0.79				0.08		0.07	0.06		50			
38	?	A	81	69	81		0.04			0.08	0.78		0.1		69			
39	Scanlen	M	130	130	1685	0.2		0.25			0.3		0.15	0.1 wheat	130			
40	Scan, Baro	M	300	75	600			0.5		0.5					75			
41	K/drift	O	500	450	10000	0.2	0.15	0.25				0.4			60	380		
42	?	A	26	26	493		0.1			0.3		0.5		0.1 Sunflowers	26			
43	?	A	60	60	160							0.7	0.25	0.05 Dry beans	60			
44	?	A	144	125	350	0.1				0.05		0.5	0.15	0.2 horses,bean	144			
45	?	A	4.7	6	0	0.1								0.9 Ostriches	6			
46	Klipfontein	L	150	145	280							0.7	0.125	0.175 wheat, pot	100	10	40	
47	Klipfontein	L	80	60	365					0.05	0.6	0.05		0.3 Vegs	55			5
48	Marlow	M	4.73	4.73	0							1			4.73			
49	?	A	150	170	3800	0.1	0.3			0.1		0.3	0.08	0.12 Potatoes	170			
50	K/drift	O	60	60	650							1			22	38		
51	Mortimer	M	199	100	4700	0.15	0.13	0.2				0.25	0.2	0.07 Dry beans	100			
52	HoughamA	L	120	120	0						0.9	0.1			100	20		
53	Bo-Grasrug	U	100	60	2998	0.9			0.06	0.04					44	16		
54	Middleton	L	100	120	1800							0.4		0.6 Ostriches	120			
55	Bar, Knuts	U	250	205	3016	0.23	0.54	0.06		0.1		0.06		0.01 Dry beans	205			
56	?	A	121	135	34	0	0.19	0.1		0.06	0.42	0.08		0.15 Unspec.	135			
57	HoughamA	L	2	2	12.3	Household consumption									2			
58	Baroda	U	29.5	29.5	2580	0.6		0.3		0.1					29.5			
59	?	A	59	30	4736	0.75				0.12			0.13		30			
60	Marlow	M	117.2	110	7900	0.3	0.2	0.2	0.15	0.15					110			
61	Knutsford	U	399	340	4200	0.4				0.08		0.12	0.2	0.2 Ostriches	340			

62 ?	A	18	0	3985	0.37	0.04	0.41		0.18						0		
63 Tarka,Scan	M	80	70	262						0.95		0.05			70		
64 Marlow	M	185	185	250						1					170	15	
65 Marlow	M	291	240	5000	0.24		0.1	0.05	0.05		0.06		0.5	Potatoes, Grapes, onions			
66 Bo-Grasrug	U	190	130	9200	0.6	0.08	0.04		0.12		0.1	0.02	0.04	Ostriches	77	18	33
67 Baroda	U	279	279	1061		0.19					0.46	0.12	0.2	Wheat, Ostriches			
68 Klipfontein	L	400	350	700					0.05		0.3	0.15	0.5	Potatoes	142	65	143
69 Teebus	U	60	40	61							0.6	0.4			40		
70 ?	A	239	110	8503	0.67	0.14			0.13			0.06			110		
71 ?	A	150	200	950			0.01			0.96	0.03				200		
72 Baroda	U	122	122	30	1										122		
73 ?	A	180	160	500						1					160		
74 Mortimer	M	179.8	154	990	0.1						0.4	0.4	0.1	wheat,bean	154		
75 ?	A	300	260	800		0.15					0.7	0.15			242	18	
76 Klipfontein	L	85	77	574		0.02		0.13	0.26		0.44	0.08	0.07	Paprika,pot	25	52	
77 Tarka	M	97.6	95	130	0.12	0.4			0.03		0.35	0.05	0.05	wheat	95		
78 ?	A	8.4	8.4	0							0.8		0.2	Pigs	8.4		

Appendix 5.4: Citrus spray programs

Pest, disease or trace element spray	Navels	Lemons	Clementine	Valencias
	Repeats per season			
Phytophtera	1.5	1.5	1.5	1.5
Trace elements: Mn, Zn, N	1	1	1	1
Trace elements: Fe	10%	-	10%	10%
Bollworm	10%	10%	10%	10%
Main: red scale, mealybug,	1	1	1	1
Thrips, incl. Main spray	2	3	2	2
Thrips, bait	2	2	2	2
Fruit size	1.5	-	2	2
Acid reduction	-	-	-	1
Black spot	-	1	-	-
Dubmite	50%	50%	50%	50%
Fungi, Cu	1	1	1	1
Weeds	4	4	4	4

Appendix 5.5 Enterprise budgets

Citrus - Gross Margin

R/ha

	Navels	Valencias	Lemons	Clementines
GROSS INCOME				
Packhouse payment	32,554	24,912	56,500	21,060
TOTAL INCOME	32,554	24,912	56,500	21,060
PRE-HARVEST COSTS				
Machine cost	997	1,095	1,147	1,170
Sundry	465	465	465	465
Pumping costs	186	186	186	186
Irrigation maintenance	1,150	1,150	1,150	1,150
Fertiliser	2,024	2,082	1,767	2,024
Pest & weed control	3,511	3,407	5,931	4,094
TOTAL PRE-HARVEST	8,333	8,385	10,647	9,089
HARVEST COST				
Machine & transport	299	263	639	461
Picking labour	1,000	988	2,132	1,540
Other	208	208	208	208
TOTAL HARVEST COST	1,507	1,459	2,979	2,209
GROSS MARGIN	22,714	15,069	42,874	9,762

Sundays River Valley

* 1999 equivalent Rands

	Replacements	New Orchards
(Packhouse payment)	-	-
TOTAL INCOME	-	-
PLANTING COST		
Clear land	300	1,360
Soil preparation	3,000	3,000
Irrigation system	7,500	12,000
Trees	9,625	9,625
Casual labour	1,364	1,364
Machine costs	1,520	3,040
PLANTING COST	23,309	30,389
MAINTENANCE		
Machine cost	-	-
Pumping cost	93	93
Irrigation maintenance	-	-
Fertiliser	63	63
Pest & weed control	922	922
Interest	3,613	4,710.24
MAINTENANCE	4,691	5,788
(GROSS MARGIN)	(28,000)	(36,177)

Crops - Gross Margin
R/ha

Great Fish River Valley
* 1999 equivalent Rands

	Dry beans			Potatoes			Maize		
	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
GROSS INCOME									
Class 1, 2 & 3	6,154	6,630	6,630	20,758	22,320	23,250	4,740	5,100	5,100
TOTAL INCOME	6,154	6,630	6,630	20,758	22,320	23,250	4,740	5,100	5,100
PRE-HARVEST COSTS									
Machine (incl. rental)	807	807	807	1,229	1,229	1,229	544	544	544
Pumping cost (flood)	15	15	15	15	16	16	16	16	16
Irrigation maintenance (flood)	44	44	44	44	44	44	44	44	44
Seed	1,026	1,026	1,026	4,800	4,800	4,800	285	285	285
Fertiliser	589	589	589	1,757	1,757	1,757	768	768	768
Pest & weed control	450	450	450	1,608	1,608	1,608	174	174	174
PRE-HARVEST	2,931	2,931	2,931	9,453	9,453	9,453	1,832	1,832	1,832
HARVEST COST									
Machine (incl. Rental)	183	183	183	358	358	358	844	890	890
Packaging	12	12	12	1,897	2,040	2,040	98	98	98
Transport	223	195	142	2,455	2,640	2,640	-	-	-
TOTAL HARVEST	418	390	337	4,711	5,038	5,038	942	989	989
GROSS MARGIN (flood irrigation)	2,805	3,309	3,362	6,594	7,829	8,759	1,966	2,279	2,279

Crops continued - Gross Margin **Great Fish River Valley**

R/ha * 1999 equivalent Rands

	Lucerne full production			Lucerne plant year			Rye grass		
	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
GROSS INCOME									
Grade 1	3,366	2,970	2,534	2,046	1,756	1,624			
Grade 2	1,318	1,706	2,214	1,026	1,048	1,296			
Grade 3	558	702	618	480	600	522			
TOTAL INCOME	5,242	5,378	5,366	3,552	3,403	3,442	-	-	-
PRE-HARVEST COSTS									
Machine (incl. rental)	19	19	19	969	969	969	374	374	374
Pumping cost (flood)	15	15	15	16	16	16	16	16	16
Irrigation maintenance (flood)	44	44	44	44	44	44	44	44	44
Seed	-	-	-	306	306	306	197	197	197
Fertiliser	296	296	296	693	693	693	304	304	304
Pest & weed control	-	-	-	293	293	293	-	-	-
PRE-HARVEST	374	374	374	2,321	2,321	2,321	935	935	935
HARVEST COST									
Machine (incl. Rental)	183	183	183	1,169	1,375	1,169	-	-	-
Packaging	12	12	12	143	143	143	-	-	-
Transport	223	195	142	-	-	-	-	-	-
TOTAL HARVEST	418	390	337	1,311	1,517	1,311	-	-	-
GROSS MARGIN (flood irrigation)	4,449	4,614	4,656	-80	-435	-191	-935	-935	-935

Livestock - Gross Margin — **Great Fish River Valley**

R/breeding unit (i.e. 50 ewes, 1 cow, 1 pair of ostriches) — * 1999 equivalent Rands

	Angora			Wool sheep					
	Pasture	Combination	Veld	Pasture	Combination	Veld		Ostrich	Dairy
MOHAIR & WOOL CLIP/ PRODUCT INCOME									
Adults	4,751	4,751	5,542	4,452	3,388	3,388	Eggs	300	-
Young goats	2,752	2,581	2,522	-	-	-	Feathers	1,279	-
Kids / Hoggets (12 months)	2,590	2,428	2,199	1,888	1,792	1,216	Milk	-	8,062
Kids (6 months) / lambs	4,853	4,550	4,167	1,826	1,309	848			
TOTAL	14,945	14,309	14,430	8,165	6,489	5,452		1,579	8,062
Less 6% marketing cost	897	859	866	490	389	327			
PRODUCT INCOME	14,049	13,451	13,564	7,675	6,100	5,124		1,579	8,062
MUTTON INCOME									
Cull animals	1,235	1,235	1,235	3,122	2,862	2,862		-	429
Lambs	2,612	2,333	1,884	10,606	8,277	4,452	Meat	3,156	-
Skins, head & trotters	-	-	-	1,110	899	627	Hides	9,428	-
MEAT INCOME	3,847	3,568	3,119	14,838	12,038	7,940		12,584	429
Less 6% marketing cost	-	-	-	890	722	476		1,075	
TOTAL GROSS INCOME	17,895	17,018	16,683	21,623	17,416	12,588		13,088	8,491
DIRECTLY ALLOCATED COST									
Purchased feed	-	-	-	-	-	-		112	823
Breeding stock replaced	750	750	750	500	500	500		-	180
Veterinary services	926	915	878	878	666	462		1,551	300
Shearing/plucking cost	487	472	451	253	244	205		119	-
Transport - livestock	-	-	-	555	450	293		4,962	-
Sundry cost	399	395	379	404	383	319		205	2,340
TOTAL ALLOCATED COST	2,563	2,532	2,458	2,589	2,243	1,779		6,949	3,643
GROSS MARGIN (breeding unit)	15,332	14,486	14,225	19,034	15,173	10,810		6,139	4,848
(GM per LSU)	1,550	1,466	1,485	1,464	1,264	989		8,296	6,464

Appendix 5.6: Citrus gross income by variety 1973-1998

Year	Navels	Lemons	Clementines	Valencia types
	1999 R/ha			
1973	23,450	58,666		20,714
1974	32,699	29,827		18,066
1975	41,307	71,208		24,421
1976	30,146	37,114		22,493
1977	42,051	43,996		32,616
1978	44,564	67,787		32,064
1979	47,503	72,526		28,858
1980	31,021	53,417		22,250
1981	28,315	64,139		26,720
1982	38,474	49,277		23,926
1983	23,479	56,523		19,882
1984	22,955	42,625		27,198
1985	28,936	83,821		29,113
1986	21,158	59,505		25,466
1987	24,051	44,260	16,419	21,802
1988	26,017	50,993	21,670	28,315
1989	27,488	55,361	19,010	24,172
1990	29,410	51,194	31,270	22,835
1991	28,440	51,565	25,696	23,937
1992	31,889	47,218	22,283	19,006
1993	30,139	43,097	14,869	22,972
1994	33,723	51,070	16,979	23,806
1995	41,629	67,511	17,704	26,447
1996	35,513	72,943	20,632	25,720
1997	30,641	58,237	20,937	23,851
1998	33,304	68,417	25,243	26,276

Appendix 5.7: Linear programming models

Type 9 **Lower Fish**

	Irrigation	Beans Flood	Beans laser	Beans CP	Beans Dragline	Beans Drip	Maize Flood	Maize laser	Maize CP	Maize Dragline	Maize Drip	Harvest grain	Sell maize
	Units	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	ha	ton
	NR	3368.46	3141.64	2276.46	2280.92	2210.46	-1831	-2005	-2887	-2912	-2983	-988.91	600
Units	Constraints												
m3	Water quota	5800	4460	3630	4140	3220	10620	8170	6640	7590	5900		
hours	Labour	239.5	227.4	185.67	205.67	185.67	71.45	59.35	17.62	37.62	17.62	34.48	
ha	Veld												
ha	Irrigated land	1	1	1	1	1	1	1	1	1	1		
ha	Count land	1	1	1	1	1	1	1	1	1	1		
ha	Count veld												
ton	Lucerne transfer												
ha	Lucerne replace flood												
ha	Lucerne replace flood laser												
ha	Lucerne replace CP												
ha	Lucerne replace DL												
ha	Lucerne replace drip												
ha	Harvest maize						-1	-1	-1	-1	-1	1	
ton	Maize grain transfer											-8	1
ha	Crop mix	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85		
Rand	t1	-808	-808	-808	-808	-808							-35.569
Rand	t2	-876	-876	-876	-876	-876							11.002
Rand	t3	206	206	206	206	206							-18.427
Rand	t4	188	188	188	188	188							58.144
Rand	t5	220	220	220	220	220							-29.285
Rand	t6	-748	-748	-748	-748	-748							116.286
Rand	Accounting												
Rand	Correction												

Type 9 cont **Lower Fish** Irrigation

		Lucerne1 Flood	Lucerne1 laser	Lucerne1 CP	Lucerne1 Dragline	Lucerne1 Drip	Lucerne2 Flood	Lucerne2 Laser	Lucerne2 CP	Lucerne2 Dragline	Lucerne2 Drip	Sell hay	Sheep Veld	Sheep Comb.
	Units	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	ton	50 ewes	50 ewes
	NR	-3831.7	-4058.7	-4923.7	-4918.7	-4989.7	-3087.4	-3314.4	-4179.4	-4174.4	-4245.4	326	10810	15173
Units	Constraints													
m3	Water quota	30880	23750	19300	22060	17160	30880	23750	19300	22060	17160			
hours	Labour	118.18	106.08	64.35	84.35	64.35	126.22	114.12	72.39	92.39	72.39		200	200
ha	Veld												218.6	139.2
ha	Irrigated land	1	1	1	1	1	1	1	1	1	1			
ha	Count land	1	1	1	1	1	1	1	1	1	1			
ha	Count veld												218.6	139.2
ton	Lucerne transfer	-10.5	-10.5	-10.5	-10.5	-10.5	-15.0	-15.0	-15.0	-15.0	-15.0	1		18.25
ha	Lucerne replace flood	-0.8					0.2							
ha	Lucerne replace flood laser		-0.8					0.2						
ha	Lucerne replace CP			-0.8					0.2					
ha	Lucerne replace DL				-0.8					0.2				
ha	Lucerne replace drip					-0.8					0.2			
ha	Harvest maize													
ton	Maize grain transfer													
ha	Crop mix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15			
Rand	t1											-25.08	1122	1227
Rand	t2											14.06	-17	-3
Rand	t3											-20.13	817	858
Rand	t4											49.01	693	719
Rand	t5											31.49	-1159	-1296
Rand	t6											-49.37	-93	-65
Rand	Accounting													
Rand	Correction													

Type 9 cont	**Lower Fish** Irrigation																	
		Sheep Pasture	Angora Veld	Angora Comb.	Angora Pasture	Hire Labour	OH Irrig	OH veld	P1	P2	P3	P4	P5	P6	Cnt	Risk	sign	RHS
	Units	50 ewes	50 ewes	50 ewes	50 ewes	month	ha	ha										
	NR	19034	13393	11507	11347	-700	-1996.7	-51.27	0	0	0	0	0	0	0	0		
Units	Constraints																	
m3	Water quota																<	1062500
hours	Labour	200	200	200	200	-176											<	0
ha	Veld		191.6	111.76				-1									<	0
ha	Irrigated land						-1										<	0
ha	Count land																<	85
ha	Count veld		191.6	111.76													<	256
ton	Lucerne transfer	47.45		14.57	34.97												<	0
ha	Lucerne replace flood																<	0
ha	Lucerne replace flood laser																<	0
ha	Lucerne replace CP																<	0
ha	Lucerne replace DL																<	0
ha	Lucerne replace drip																<	0
ha	Harvest maize																<	0
ton	Maize grain transfer																<	0
ha	Crop mix																<	0
Rand	t1	1561	354	368	379				1								>	0
Rand	t2	-50	-1135	-1183	-1216					1							>	0
Rand	t3	1199	-1489	-1552	-1596						1						>	0
Rand	t4	1037	-1700	-1772	-1822							1					>	0
Rand	t5	-1561	409	426	439								1				>	0
Rand	t6	-195	2837	2956	3040									1			>	0
Rand	Accounting								-2	-2	-2	-2	-2	-2	1		=	0
Rand	Correction														0.23	-1	=	0

Type 10 **Lower Fish**
Stock farms

		Beans Flood	Beans laser	Beans CP	Beans Dragline	Beans Drip	Maize Flood	Maize laser	Maize CP	Maize Dragline	Maize Drip	Harvest grain	Sell maize
	Units	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	ha	ton
	NR	3368.46	3141.64	2276.46	2280.92	2210.46	-1831	-2005	-2887	-2912	-2983	-988.91	600
Units	Constraints												
m3	Water quota	5800	4460	3630	4140	3220	10620	8170	6640	7590	5900		
hours	Labour	239.5	227.4	185.67	205.67	185.67	71.45	59.35	17.62	37.62	17.62	34.48	
ha	Veld												
ha	Irrigated land	1	1	1	1	1	1	1	1	1	1		
ha	Count land	1	1	1	1	1	1	1	1	1	1		
ha	Count veld												
ton	Lucerne transfer												
ha	Lucerne replace flood												
ha	Lucerne replace flood laser												
ha	Lucerne replace CP												
ha	Lucerne replace DL												
ha	Lucerne replace drip												
ha	Harvest maize						-1	-1	-1	-1	-1	1	
ton	Maize grain transfer											-8	1
ha	Crop mix	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85		
Rand	t1	-808	-808	-808	-808	-808							-35.569
Rand	t2	-876	-876	-876	-876	-876							11.002
Rand	t3	206	206	206	206	206							-18.427
Rand	t4	188	188	188	188	188							58.144
Rand	t5	220	220	220	220	220							-29.285
Rand	t6	-748	-748	-748	-748	-748							116.286
Rand	Accounting												
Rand	Correction												

Type 10 cont **Lower Fish** Stock farms

		Lucerne1 Flood	Lucerne1 laser	Lucerne1 CP	Lucerne1 Dragline	Lucerne1 Drip	Lucerne2 Flood	Lucerne2 Laser	Lucerne2 CP	Lucerne2 Dragline	Lucerne2 Drip	Sell hay	Sheep Veld	Sheep Comb.
	Units	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	ton	50 ewes	50 ewes
	NR	-3831.7	-4058.7	-4923.7	-4918.7	-4989.7	-3087.4	-3314.4	-4179.4	-4174.4	-4245.4	326	10810	15173
Units	Constraints													
m3	Water quota	30880	23750	19300	22060	17160	30880	23750	19300	22060	17160			
hours	Labour	118.18	106.08	64.35	84.35	64.35	126.22	114.12	72.39	92.39	72.39		200	200
ha	Veld												218.6	139.2
ha	Irrigated land	1	1	1	1	1	1	1	1	1	1			
ha	Count land	1	1	1	1	1	1	1	1	1	1			
ha	Count veld												218.6	139.2
ton	Lucerne transfer	-10.5	-10.5	-10.5	-10.5	-10.5	-15.0	-15.0	-15.0	-15.0	-15.0	1		18.25
ha	Lucerne replace flood	-0.8					0.2							
ha	Lucerne replace flood laser		-0.8					0.2						
ha	Lucerne replace CP			-0.8					0.2					
ha	Lucerne replace DL				-0.8					0.2				
ha	Lucerne replace drip					-0.8					0.2			
ha	Harvest maize													
ton	Maize grain transfer													
ha	Crop mix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15			
Rand	t1											-25.08	1122	1227
Rand	t2											14.06	-17	-3
Rand	t3											-20.13	817	858
Rand	t4											49.01	693	719
Rand	t5											31.49	-1159	-1296
Rand	t6											-49.37	-93	-65
Rand	Accounting													
Rand	Correction													

Type10 Lower Fish
cont Stock farms

Units	Constraints	Sheep Pasture	Angora Veld	Angora Comb.	Angora Pasture	Hire Labour	OH Irrig	OH veld	P1	P2	P3	P4	P5	P6	Cnt	Risk	sign	RHS
	Units	50 ewes	50 ewes	50 ewes	50 ewes	month	ha	ha										
	NR	19034	13393	11507	11347	-700	-1996.7	-51.27	0	0	0	0	0	0	0	0		
m3	Water quota																<	1062500
hours	Labour	200	200	200	200	-176											<	0
ha	Veld		191.6	111.76				-1									<	0
ha	Irrigated land						-1										<	0
ha	Count land																<	85
ha	Count veld		191.6	111.76													<	2540
ton	Lucerne transfer	47.45		14.57	34.97												<	0
ha	Lucerne replace flood																<	0
ha	Lucerne replace flood laser																<	0
ha	Lucerne replace CP																<	0
ha	Lucerne replace DL																<	0
ha	Lucerne replace drip																<	0
ha	Harvest maize																<	0
ton	Maize grain transfer																<	0
ha	Crop mix																<	0
Rand	t1	1561	354	368	379				1								>	0
Rand	t2	-50	-1135	-1183	-1216					1							>	0
Rand	t3	1199	-1489	-1552	-1596						1						>	0
Rand	t4	1037	-1700	-1772	-1822							1					>	0
Rand	t5	-1561	409	426	439								1				>	0
Rand	t6	-195	2837	2956	3040									1			>	0
Rand	Accounting								-2	-2	-2	-2	-2	-2	1		=	0
Rand	Correction														0.23	-1	=	0

Type11 Lower Fish

Farm business

		Potatoes Flood	Potatoes Laser	Potatoes CP	Potatoes Dragline	Potatoes Drip	Beans Flood	Beans laser	Beans CP	Beans Draglines	Beans Drip	Maize Flood
	Units	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha
	NR	8766	8539	7674	7678	7608	3368.46	3141.64	2276.46	2280.92	2210.46	-1831
Units	Constraints											
m3	Water quota	11960	9200	7480	8540	6640	5800	4460	3630	4140	3220	10620
hours	Labour	547.2	535.1	493.37	513.37	493.37	239.5	227.4	185.67	205.67	185.67	71.45
ha	Veld											
ha	Irrigated land	1	1	1	1	1	1	1	1	1	1	1
ha	Count land	1	1	1	1	1	1	1	1	1	1	1
ha	Count veld											
ton	Lucerne transfer											
ha	Lucerne replace flood											
ha	Lucerne replace flood laser											
ha	Lucerne replace CP											
ha	Lucerne replace DL											
ha	Lucerne replace drip											
ha	Harvest maize											-1
ton	Maize grain transfer											
ha	Crop mix	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85
Rand	t1	4014	4014	4014	4014	4014	-808	-808	-808	-808	-808	
Rand	t2	-2417	-2417	-2417	-2417	-2417	-876	-876	-876	-876	-876	
Rand	t3	-1563	-1563	-1563	-1563	-1563	206	206	206	206	206	
Rand	t4	-2481	-2481	-2481	-2481	-2481	188	188	188	188	188	
Rand	t5	-754	-754	-754	-754	-754	220	220	220	220	220	
Rand	t6	3200	3200	3200	3200	3200	-748	-748	-748	-748	-748	
Rand	Accounting											
Rand	Correction											

Type11 cont **Lower Fish**
Farm business

Units	Constraints	Maize laser	Maize CP	Maize Draglines	Maize Drip	Harvest grain	Sell maize	Lucerne1 Flood	Lucerne1 laser	Lucerne1 CP	Lucerne1 Draglines	Lucerne1 Drip
	Units	1ha	1ha	1ha	1ha	ha	ton	1ha	1ha	1ha	1ha	1ha
	NR	-2005	-2887	-2912	-2983	-988.91	600	-3831.67	-4058.67	-4923.67	-4918.67	-4989.67
mm	Water quota	8170	6640	7590	5900			30880	23750	19300	22060	17160
hours	Labour	59.35	17.62	37.62	17.62	34.48		118.18	106.08	64.35	84.35	64.35
ha	Veld											
ha	Irrigated land	1	1	1	1			1	1	1	1	1
ha	Count land	1	1	1	1			1	1	1	1	1
ha	Count veld											
ton	Lucerne transfer							-10.5	-10.5	-10.5	-10.5	-10.5
ha	Lucerne replace flood							-0.8				
ha	Lucerne replace flood laser								-0.8			
ha	Lucerne replace CP									-0.8		
ha	Lucerne replace DL										-0.8	
ha	Lucerne replace drip											-0.8
ha	Harvest maize	-1	-1	-1	-1	1						
ton	Maize grain transfer					-8	1					
ha	Crop mix	-0.85	-0.85	-0.85	-0.85			0.15	0.15	0.15	0.15	0.15
Rand	t1						-35.569					
Rand	t2						11.002					
Rand	t3						-18.427					
Rand	t4						58.144					
Rand	t5						-29.285					
Rand	t6						116.286					
Rand	Accounting											
Rand	Correction											

Type11 cont **Lower Fish**
Farm business

Units	Constraints	Lucerne2 Flood	Lucerne2 Laser	Lucerne2 CP	Lucerne2 Draglines	Lucerne2 Drip	Sell hay	Sheep Veld	Sheep Comb.	Sheep Pasture	Angora Veld	Angora Comb.
	Units	1ha	1ha	1ha	1ha	1ha	ton	50 ewes	50 ewes	50 ewes	50 ewes	50 ewes
	NR	-3087.4	-3314.4	-4179.4	-4174.4	-4245.4	326	10810	15173	19034	13393	11507
mm	Water quota	30880	23750	19300	22060	17160						
hours	Labour	126.22	114.12	72.39	92.39	72.39		200	200	200	200	200
ha	Veld							218.6	139.2		191.6	111.76
ha	Irrigated land	1	1	1	1	1						
ha	Count land	1	1	1	1	1						
ha	Count veld							218.6	139.2		191.6	111.76
ton	Lucerne transfer	-15.0	-15.0	-15.0	-15.0	-15.0	1		18.25	47.45		14.57
ha	Lucerne replace flood	0.2										
ha	Lucerne replace flood laser		0.2									
ha	Lucerne replace CP			0.2								
ha	Lucerne replace DL				0.2							
ha	Lucerne replace drip					0.2						
ha	Harvest maize											
ton	Maize grain transfer											
ha	Crop mix	0.15	0.15	0.15	0.15	0.15						
Rand	t1						-25.08	1122	1227	1561	354	368
Rand	t2						14.06	-17	-3	-50	-1135	-1183
Rand	t3						-20.13	817	858	1199	-1489	-1552
Rand	t4						49.01	693	719	1037	-1700	-1772
Rand	t5						31.49	-1159	-1296	-1561	409	426
Rand	t6						-49.37	-93	-65	-195	2837	2956
Rand	Accounting											
Rand	Correction											

Type11 cont **Lower Fish**
Farm business

Units		Angora Pasture	Hire Labour	OH Irrig	OH veld	P1	P2	P3	P4	P5	P6	Cnt	Risk	sign	RHS
	Units	50 ewes	month	ha	ha										
	NR	11347	-700	-1996.73	-51.27	0	0	0	0	0	0	0	0		
Units	**Constraints**														
mm	Water quota													<	1750000
hours	Labour	200	-176											<	0
ha	Veld				-1									<	0
ha	Irrigated land			-1										<	0
ha	Count land													<	140
ha	Count veld													<	7900
ton	Lucerne transfer	34.97												<	0
ha	Lucerne replace flood													<	0
ha	Lucerne replace flood laser													<	0
ha	Lucerne replace CP													<	0
ha	Lucerne replace DL													<	0
ha	Lucerne replace drip													<	0
ha	Harvest maize													<	0
ton	Maize grain transfer													<	0
ha	Crop mix													<	0
Rand	t1	379				1								>	0
Rand	t2	-1216					1							>	0
Rand	t3	-1596						1						>	0
Rand	t4	-1822							1					>	0
Rand	t5	439								1				>	0
Rand	t6	3040									1			>	0
Rand	Accounting					-2	-2	-2	-2	-2	-2	1		=	0
Rand	Correction											0.23	-1	=	0

Type 12	Lower Fish Dairy	Dairy	Rye Flood	Rye laser	Rye CP	Rye Dragline	Rye Drip	Maize Flood	Maize laser	Maize CP	Maize Dragline	Maize Drip
	Units	1cow	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha	1ha
	NR	4847.94	-934	-1108	-1990	-2015	-2086	-1831	-2005	-2887	-2912	-2983
Units	**Constraints**											
m3	Water quota		12940	9950	8090	9240	7190	10620	8170	6640	7590	5900
hours	Labour	50	69.1	57	15.27	33.27	15.27	71.45	59.35	17.62	37.62	17.62
ha	Irrigated land		1	1	1	1	1	1	1	1	1	1
ha	Count land		1	1	1	1	1	1	1	1	1	1
ton	Lucerne transfer	5.35										
ha	Lucerne replace flood											
ha	Lucerne replace flood laser											
ha	Lucerne replace CP											
ha	Lucerne replace DL											
ha	Lucerne replace drip											
ha	Harvest maize							-1	-1	-1	-1	-1
ton	Maize grain transfer	1.58										
ton	Roughage transfer	0.49										
ton	Silage transfer	3.42										
ton	Rye transfer	2.4	-19	-19	-19	-19	-19					
ha	Crop mix		-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85
Rand	t1	-483										
Rand	t2	-976										
Rand	t3	1638										
Rand	t4	536										
Rand	t5	447										
Rand	t6	-1116										
Rand	Accounting											
Rand	Correction											

Type 12 cont.	**Lower Fish Dairy**	Maize silage	Harvest grain	Sell maize	Lucerne1 Flood	Lucerne1 laser	Lucerne1 CP	Lucerne1 Dragline	Lucerne1 Drip	Lucerne2 Flood	Lucerne2 Laser	Lucerne2 CP
	Units	ha	ha	ton	ha	ha	ha	ha	ha	ha	ha	ha
	NR	-526.78	-945	600	-3831.67	-4058.67	-4923.67	-4918.67	-4989.67	-3075.4	-3302.4	-4167.4
Units	Constraints											
m3	Water quota				30880	23750	19300	22060	17160	30880	23750	19300
hours	Labour	7.4	34.48		118.18	106.08	64.35	84.35	64.35	126.22	114.12	72.39
ha	Irrigated land				1	1	1	1	1	1	1	1
ha	Count land				1	1	1	1	1	1	1	1
ton	Lucerne transfer				-10.5	-10.5	-10.5	-10.5	-10.5	-15.0	-15.0	-15.0
ha	Lucerne replace flood				-0.8					0.2		
ha	Lucerne replace flood laser					-0.8					0.2	
ha	Lucerne replace CP						-0.8					0.2
ha	Lucerne replace DL							-0.8				
ha	Lucerne replace drip								-0.8			
ha	Harvest maize	1	1									
ton	Maize grain transfer		-8	1								
ton	Roughage transfer		-2.5									
ton	Silage transfer	-85										
ton	Rye transfer											
ha	Crop mix				0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Rand	t1			-35.569								
Rand	t2			11.002								
Rand	t3			-18.427								
Rand	t4			58.144								
Rand	t5			-29.285								
Rand	t6			116.286								
Rand	Accounting											
Rand	Correction											

Type 12 cont.	**Lower Fish Dairy**	Lucerne2 Dragline	Lucerne2 Drip	Sell hay	Hire Labour	OH Irrig	P1	P2	P3	P4	P5	P6	Coun t risk	Risk		
	Units	ha	ha	ton	month	ha										
	NR	-4162.4	-4233.4	326	-700	-1996.73	0	0	0	0	0	0	0	0		
Units	Constraints															
m3	Water quota	22060	17160												<	1062500
hours	Labour	92.39	72.39		-176										<	0
ha	Irrigated land	1	1			-1									<	0
ha	Count land	1	1												<	85
ton	Lucerne transfer	-15.0	-15.0	1											<	0
ha	Lucerne replace flood														<	0
ha	Lucerne replace flood laser														<	0
ha	Lucerne replace CP														<	0
ha	Lucerne replace DL	0.2													<	0
ha	Lucerne replace drip		0.2												<	0
ha	Harvest maize														<	0
ton	Maize grain transfer														<	0
ton	Roughage transfer														<	0
ton	Silage transfer														<	0
ton	Rye transfer														<	0
ha	Crop mix	0.15	0.15												<	0
Rand	t1			-25.08			1								>	0
Rand	t2			14.06				1							>	0
Rand	t3			-20.13					1						>	0
Rand	t4			49.01						1					>	0
Rand	t5			31.49							1				>	0
Rand	t6			-49.37								1			>	0
Rand	Accounting						-2	-2	-2	-2	-2	-2	1		=	0
Rand	Correction												0.23	-1	=	0

Type 13 Sundays
Small mixed farms

		Year1	Year2	Year3	Navels	Lemons	Clems	Valencia	Dairy	Rye Flood	Rye laser	Rye Dragline
	Units	ha	ha	ha	ha	ha	ha	ha	cow	ha	ha	ha
	NR	-28000	-2976	-2984	22714	34299.2	9762	15069	3709	-934	-1108	-2015
Units	Constraints											
m3	Water quota	6590	6590	6590	13180	13180	13180	13180		12940	9950	9240
hours	Labour	259	132.7	152.7	423.5	685	566	393.5	50	69.1	57	33.27
ha	Irrigated land	1	1	1	1	1	1	1		0.5	0.5	0.5
ha	Count land	1	1	1	1	1	1	1		1	1	1
%	Replanting 1	-0.96	0.04	0.04	0.04	0.04	0.04	0.04				
%	Replanting 2	0.04	-0.96	0.04	0.04	0.04	0.04	0.04				
%	Replanting 3	0.04	0.04	-0.96	0.04	0.04	0.04	0.04				
ton	Lucerne transfer								5.35			
ton	Rye transfer								2.4	-19	-19	-19
ha	Lucerne replace flood											
ha	Lucerne replace flood laser											
ha	Lucerne replace DL											
ha	Lucerne replace drip											
Rand	t1				14949	16026	0	3946				
Rand	t2				-1533	-3083	0	-2662				
Rand	t3				-4239	7639	0	1808				
Rand	t4				5920	-7223	0	-986				
Rand	t5				-9075	23	0	-5030				
	...											
Rand	t18				2959	16443	-428	808				
Rand	t19				-1913	1737	-123	-1061				
Rand	t20				750	11917	4183	1364				
Rand	Accounting											
Rand	Correction											

Type 13 cont. — Sundays — Small mixed farms

		Rye Drip	Lucerne1 Flood	Lucerne1 laser	Lucerne1 Dragline	Lucerne1 Drip	Lucerne2 Flood	Lucerne2 Laser	Lucerne2 Dragline	Lucerne2 Drip	Sell hay	Potato Flood
	Units	ha	ha	ha	ha	ha	ha	ha	ha	ha	ton	ha
	NR	-2086	-3831.67	-4058.67	-4918.67	-4989.67	-3075.4	-3302.4	-4162.4	-4233.4	326	8766
Units	Constraints											
m3	Water quota	7190	30880	23750	22060	17160	30880	23750	22060	17160		11960
hours	Labour	15.27	118.18	106.08	84.35	64.35	126.22	114.12	92.39	72.39		547.2
ha	Irrigated land	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5
ha	Count land	1	1	1	1	1	1	1	1	1		1
%	Replanting 1											
%	Replanting 2											
%	Replanting 3											
ton	Lucerne transfer		-10.5	-10.5	-10.5	-10.5	-15.0	-15.0	-15.0	-15.0	1.0	
ton	Rye transfer	-19										
ha	Lucerne replace flood		-0.8				0.2					
ha	Lucerne replace flood laser			-0.8				0.2				
ha	Lucerne replace DL				-0.8				0.2			
ha	Lucerne replace drip					-0.8				0.2		
Rand	t1										-25.08	4014
Rand	t2										14.06	-2417
Rand	t3										-20.13	-1563
Rand	t4										49.01	-2481
Rand	t5										31.49	-754
	…											
Rand	t18										49.01	-2481
Rand	t19										31.49	-754
Rand	t20										-49.37	3200
Rand	Accounting											
Rand	Correction											

Type 13 cont. — Sundays, Small mixed farms

Units		Potato Laser	Potato Dragline	Potato Drip	Hire labour	OH irrig.	P1	P2	P3	P4	P5	...	P18	P19	P20
	Units	ha	ha	ha	month	ha									
	NR	8539	7678	7608	-700	-5691	0	0	0	0	0		0	0	0
Units	Constraints														
m3	Water quota	9200	8540	6640											
hours	Labour	535.1	513.37	493.37	-176										
ha	Irrigated land	0.5	0.5	0.5		-1									
ha	Count land	1	1	1											
%	Replanting 1														
%	Replanting 2														
%	Replanting 3														
ton	Lucerne transfer														
ton	Rye transfer														
ha	Lucerne replace flood														
ha	Lucerne replace flood laser														
ha	Lucerne replace DL														
ha	Lucerne replace drip														
Rand	t1	4014	4014	4014			1								
Rand	t2	-2417	-2417	-2417				1							
Rand	t3	-1563	-1563	-1563					1						
Rand	t4	-2481	-2481	-2481						1					
Rand	t5	-754	-754	-754							1				
	...											. . .			
Rand	t18	-2481	-2481	-2481									1		
Rand	t19	-754	-754	-754										1	
Rand	t20	3200	3200	3200											1
Rand	Accounting						-2	-2	-2	-2	-2		-2	-2	-2
Rand	Correction														

Type 13 cont. Sundays Small mixed farms

		Count risk	Risk		
	Units				
	NR	0	0		
Units	Constraints				
m3	Water quota			<	261000
hours	Labour			<	0
ha	Irrigated land			<	0
ha	Count land			<	29
%	Replanting 1			<	0
%	Replanting 2			<	0
%	Replanting 3			<	0
ton	Lucerne transfer			<	0
ton	Rye transfer			<	0
ha	Lucerne replace flood			<	0
ha	Lucerne replace flood laser			<	0
ha	Lucerne replace DL			<	0
ha	Lucerne replace drip			<	0
Rand	t1			>	0
Rand	t2			>	0
Rand	t3			>	0
Rand	t4			>	0
Rand	t5			>	0
	…				
Rand	t18			>	0
Rand	t19			>	0
Rand	t20			>	0
Rand	Accounting	1		=	0
Rand	Correction	0.06	-1	=	0

Type 14 Sundays

Large stable farms

Units		Year1	Year2	Year3	Navels	Lemons	Clems	Valencia	Hire labour	OH irrig.	P1	P2	P3	P4
	Units	ha	ha	ha	ha	ha	ha	ha	month	ha				
	NR	-28000	-2976	-2984	22714	34299.2	9762	15069	-700	-5691	0	0	0	0
Units	Constraints													
m3	Water quota	6590	6590	6590	13180	13180	13180	13180						
hours	Labour	259	132.7	152.7	423.5	685	566	393.5	-176					
ha	Irrigated land	1	1	1	1	1	1	1		-1				
ha	Count land	1	1	1	1	1	1	1						
%	Replanting 1	-0.98	0.02	0.02	0.02	0.02	0.02	0.02						
%	Replanting 2	0.02	-0.98	0.02	0.02	0.02	0.02	0.02						
%	Replanting 3	0.02	0.02	-0.98	0.02	0.02	0.02	0.02						
Rand	t1				14949	16026		3946			1			
Rand	t2				-1533	-3083		-2662				1		
Rand	t3				-4239	7639		1808					1	
Rand	t4				5920	-7223		-986						1
Rand	t5				-9075	23		-5030						
	...				.	.	.	.						
					.	.	.	.						
					.	.	.	.						
Rand	t18				2959	16443	-428	808						
Rand	t19				-1913	1737	-123	-1061						
Rand	t20				750	11917	4183	1364						
Rand	Accounting										-2	-2	-2	-2
Rand	Correction													

Type 14 Sundays
cont. Large stable farms

Units		P5	...	P18	P19	P20	Cnt	Risk		
	Units									
	NR	0		0	0	0	0	0		
Units	Constraints									
m3	Water quota								<	1008000
hours	Labour								<	0
ha	Irrigated land								<	0
ha	Count land								<	112
%	Replanting 1								<	0
%	Replanting 2								<	0
%	Replanting 3								<	0
Rand	t1								>	0
Rand	t2								>	0
Rand	t3								>	0
Rand	t4								>	0
Rand	t5	1							>	0
	...		. . .							
Rand	t18			1					>	0
Rand	t19				1				>	0
Rand	t20					1			>	0
Rand	Accounting	-2		-2	-2	-2	1		=	0
Rand	Correction						0.06	-1	=	0

Type 15 Sundays
Small expanding citrus farms

		Year1	Year2	Year3	Navels	Lemons	Clems	Potato Valencia	Potato Flood	Potato Laser	Potato Dragline	Potato Drip
	Units	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
	NR	-36177	-2976	-2984	22714	34299.2	9762	15069	8766	8539	7678	7608
Units	Constraints											
m3	Water quota	6590	6590	6590	13180	13180	13180	13180	11960	9200	8540	6640
hours	Labour	259	132.7	152.7	423.5	685	566	393.5	547.2	535.1	513.37	493.37
ha	Irrigated land	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5
ha	Count land	1	1	1	1	1	1	1	1	1	1	1
%	Replanting 1	-0.92	0.08	0.08	0.08	0.08	0.08	0.08				
%	Replanting 2	0.08	-0.92	0.08	0.08	0.08	0.08	0.08				
%	Replanting 3	0.08	0.08	-0.92	0.08	0.08	0.08	0.08				
Rand	t1				14949	16026	0	3946	4014	4014	4014	4014
Rand	t2				-1533	-3083	0	-2662	-2417	-2417	-2417	-2417
Rand	t3				-4239	7639	0	1808	-1563	-1563	-1563	-1563
Rand	t4				5920	-7223	0	-986	-2481	-2481	-2481	-2481
Rand	t5				-9075	23	0	-5030	-754	-754	-754	-754
	...				.	.	.	.	.	.	.	.
					.	.	.	.	.	.	.	.
					.	.	.	.	.	.	.	.
Rand	t18				2959	16443	-428	808	-2481	-2481	-2481	-2481
Rand	t19				-1913	1737	-123	-1061	-754	-754	-754	-754
Rand	t20				750	11917	4183	1364	3200	3200	3200	3200
Rand	Accounting											
Rand	Correction											

Type 15 cont. Sundays
Small expanding citrus farms

		Hire labour	OH irrig.	P1	P2	P3	P4	P5	…	P18	P19	P20	Cnt	Risk		
	Units	month	ha													
	NR	-700	-5691	0	0	0	0	0		0	0	0	0	0		
Units	Constraints															
m3	Water quota														<	450000
hours	Labour	-176													<	0
ha	Irrigated land		-1												<	0
ha	Count land														<	50
%	Replanting 1														<	0
%	Replanting 2														<	0
%	Replanting 3														<	0
Rand	t1			1											>	0
Rand	t2				1										>	0
Rand	t3					1									>	0
Rand	t4						1								>	0
Rand	t5							1							>	0
	…								. . .							
Rand	t18									1					>	0
Rand	t19										1				>	0
Rand	t20											1			>	0
Rand	Accounting			-2	-2	-2	-2	-2		-2	-2	-2	1		=	0
Rand	Correction												0.064	-1	=	0

Type 16 Sundays
Large expanding
citrus farms

									Hire					
		Year1	Year2	Year3	Navels	Lemons	Clems	Valencias	labour	OH irrig.	P1	P2	P3	P4
	Units	ha	ha	ha	ha	ha	ha	ha	month	ha				
	NR	-36177	-2976	-2984	22714	34299.2	9762	15069	-700	-5691	0	0	0	0
Units	Constraints													
m3	Water quota	6590	6590	6590	13180	13180	13180	13180						
hours	Labour	259	132.7	152.7	423.5	685	566	393.5	-176					
ha	Irrigated land	1	1	1	1	1	1	1		-1				
ha	Count land	1	1	1	1	1	1	1						
%	Replanting 1	-0.92	0.08	0.08	0.08	0.08	0.08	0.08						
%	Replanting 2	0.08	-0.92	0.08	0.08	0.08	0.08	0.08						
%	Replanting 3	0.08	0.08	-0.92	0.08	0.08	0.08	0.08						
Rand	t1				14949	16026	0	3946			1			
Rand	t2				-1533	-3083	0	-2662				1		
Rand	t3				-4239	7639	0	1808					1	
Rand	t4				5920	-7223	0	-986						1
Rand	t5				-9075	23	0	-5030						
	...				.	.	.	.						
					.	.	.	.						
					.	.	.	.						
Rand	t18				2959	16443	-428	808						
Rand	t19				-1913	1737	-123	-1061						
Rand	t20				750	11917	4183	1364						
Rand	Accounting										-2	-2	-2	-2
Rand	Correction													

Type 16 cont. — Sundays — Large expanding citrus farms

Units	Constraints	P5	...	P18	P19	P20	Cnt	Risk	Sign	RHS
	Units									
	NR	0		0	0	0	0	0		
m3	Water quota								<	1755000
hours	Labour								<	0
ha	Irrigated land								<	0
ha	Count land								<	195
%	Replanting 1								<	0
%	Replanting 2								<	0
%	Replanting 3								<	0
Rand	t1								>	0
Rand	t2								>	0
Rand	t3								>	0
Rand	t4								>	0
Rand	t5	1							>	0
	...									
Rand	t18			1					>	0
Rand	t19				1				>	0
Rand	t20					1			>	0
Rand	Accounting	-2		-2	-2	-2	1		=	0
Rand	Correction						0.06	-1	=	0