The Value of Water as an Economic Resource in the Greater Letaba River Catchment

Report to the
Water Research Commission

by

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DEDICATION

The finalisation of this report was delayed due to circumstances and the personal health of the lead author, Chris Williams. Through his personal perseverance a final copy was eventually handed to the Water Research Commission but, sadly, Chris passed away in July 2008, before this report was published.

EXECUTIVE SUMMARY

BACKGROUND

Nieuwoudt, Backeberg and Du Plessis (2004) states "As South Africa is a drought-prone, water poor region it seems probable that water shortages will redirect economic development. As water scarcity increases, the need to manage water as a national asset and for overall social benefit becomes imperative. During the past number of years the South African Water Research Commission initiated a number of economic research projects aimed at determining the value of water in different sectors of the economy and in different parts of the country."

This project is one of those initiatives and it explores the value of water as an economic resource in the Groot, Middle and Klein Letaba river catchments.

The Letaba water management area lies entirely within the Limpopo Province and forms an integral part of the Limpopo Basin. The study area comprises the Groot, Klein and Middle Letaba catchments. The Groot Letaba area forms part of the Lowveld Region of the Limpopo Province and represents the heart of the provincial economy, whilst the Klein and Middle Letaba can be classified as rural with a strong bias towards agriculture and retail.

The overall picture of the study area is that of a region which is largely arid, which is mainly low income, but which has opportunities for commercial farming and forestry. The need for water is an important issue in every part of the region and the need for effective water management is great. The ability to obtain economic values for water, and to use these for management decision support, is clearly a matter of importance.

OBJECTIVES AND HYPOTHESES

The aims and objectives of this study are, amongst others, to:

i Determine the water balance in the catchment; taking into account the confluence of the Klein, Middle and Groot Letaba;
ii Determine the water demand schedules for the irrigated agriculture, forestry, eco-systems and household sectors;
iii Use these demand schedules to determine the economic value[1] of water by establishing willingness-to-pay;
iv Determine the supply schedules for the same sectors in order to compare the cost of water with its value; and
v Generate water use scenarios and evaluate their impact.

[1] When we consider the value of water in this study, it is always the economic value which is being referred to. The economic value encompasses the complete value of water to the economy, not just the infrastructural costs associated with making water available to end users. In essence, it also incorporates the "value of the water drop"; the value of water itself as a commodity.

The following hypotheses underpin the research described in this report:

i *Is it necessary to research the value of water because*
- water is scarce
- South Africa's water laws have recently changed, and
- knowledge of the value of water can assist with allocation decisions?

ii *The value of water is embodied in the user's willingness to pay, which is revealed by the consumer surplus associated water demand schedules associated with different uses of water, where*
- water demand may be direct (i.e. municipal and ecological usage), or
- derived (i.e. industrial, agricultural and forestry usage.

iii *Water demand schedules can be synthesised using*
- Contingent Valuation techniques for direct demand situations, and
- Linear Programming and Crop Production Functions for derived demand situations.

iv *Water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques.*

The Letaba River Catchment with its varied climatic zones, diverse agriculture and range of municipal areas provides a rich fabric for exploring the objectives above and for testing the validity of the hypotheses put forward.

METHODOLOGICAL APPROACH

The value of an economic good can be approximated by a measure of users' willingness-to-pay to have the good rather than go without it. This value can be expressed in terms of the money that can be exchanged for the commodity provided an explicit market for it exists. Hence, if it is possible to estimate a market demand curve, the value of a good may be approximated as willingness-to-pay by measuring consumer surplus.

These water demand curves are simulated through the use of various modelling techniques. The approach employed is to use contingent valuation methods for direct demand (municipal water), and enterprise budgets and linear programming, or enterprise budgets with crop water production functions for derived demand (forestry and agricultural water). For the purpose of integrating these curves and evaluating scenarios, a model which allocates water according to the principle of maximisation of social welfare is used.

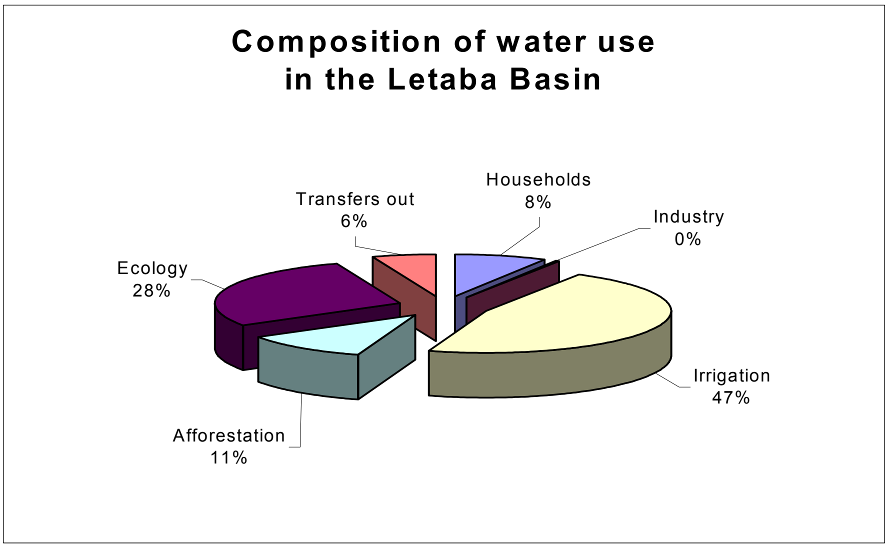
The output of the models is water demand schedules for different water user groups, from which consumer's surpluses and water value are imputed. The scenario evaluation model reallocates water and sets appropriate prices, as well as provides a benchmark which indicates the extent to which the welfare-maximising objective of the exercise is met.

SUMMARY OF RESULTS

The base date for this study is 2002. There have been considerable changes in some of the critical inputs to the research, so the reader should be cautious about trying to transport the results presented below directly into the present without careful consideration. After discussion of the water balance, results are discussed in terms of the major water use sectors considered in the study. It should be noted that values for water presented represent annual rentals for water, and not capitalised values (which might be equated with the value of associated water rights).

Water Balance

The distribution of water use within the catchment was found to be as represented in the diagram below.



The total water use was estimated to be 316.5 Mm^3 and in terms of annual run-off there is still an annual surplus of 183 Mm^3.

According to the National Water Resource Strategy the base scenario for the project area in terms of use would be 226 Mm^3 in 2023 and the high scenario 228 Mm^3. It is therefore evident that presently there is no surplus yield available and that the position can only deteriorate in future if no extra provision is made to increase the yield.

Agricultural Water

The linear programming approach used to develop water demand schedules for agricultural water use provided water demand schedules which are consistent with existing norms, and which deliver results consistent with other exercises in this field.

Some detail is lost in linearising the schedules, but this is necessary in order to be able to present them to the integrating model, as well as to provide some smoothing of the intrinsically lumpy curves.

These water demand schedules demonstrate a value for water of R0,97/Mm^3 at current (2002) usage level of 151 Mm^3. When the value of water is imputed from the value of the land, based on the net return of the enterprise, a figure of R0,80/Mm^3 is obtained, which is consistent with the value developed from the water demand schedules.

Forestry Water

Water demand schedules for forestry were developed using enterprise budgets and water production functions for gum and pine in the area. Water value was calculated in terms of stream-flow reduction and is set out in the table below:

	Area Planted	Streamflow Reduction	Annual Values
	ha	Mm^3	R/m^3/annum
GUM	29 365	21.513	0.27
PINE	19 935	14.768	0.66

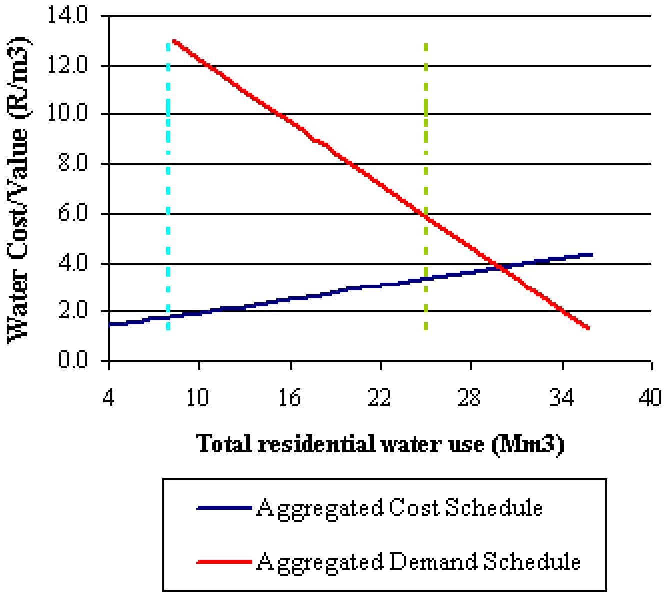
The water values for gum seem to be uncharacteristically low when compared with those for pine. A study by Tewari (2003) in KwaZulu-Natal shows water value for gum roughly twice those for pine. This could be attributed to the fact that the forestry budgets for 2002 used in this study reflect a very low value of attainable profit compared with that of pine for similar streamflow reduction values.

Municipal Water

The value of municipal water was determined by means of a contingent valuation survey where user reaction to the change in price of water is tested directly in the field. The water demand schedule obtained, after aggregation across income levels, and smoothing by linear regression, are presented below, together with the relevant aggregated cost curve.

It can be seen that at current usage of 25 Mm^3 the value of water is higher than the costs, as is the case in other water use sectors. This is to be expected, as some water is still provided at sub-economic costs. However, it is found that municipal water tariffs are much closer to their economic values, despite the fact that some users are subject to a tariff clearing prices than is the case in other sectors.

The value of water at current usage is seen to be about R5,72/kl with costs of some R3,50/kl.



Ecological water

In determining the value of water for agriculture and municipal use, the water is valued once it has been abstracted from the river and put to specific use. In the case of the ecology water the value of the water which is not abstracted, but remains in the river, is determined. This is done by considering the services the river provides, and the products which it nurtures and are used by neighbouring communities. In addition, it needs to be remembered that Letaba enters and runs through the Kruger National Park, where it is able to provide a different set of services. Whilst the value of water once it reaches the Kruger Park is not of direct concern in valuing ecological water in the Letaba catchment, it is import to have some appreciation of what the value of this water in the Kruger Park might be. The value of water in the Kruger Park was therefore estimated using a desk-top study analysing work of others already performed in this area, to arrive at a value of the water inside the park. A methodology based on the tourism potential of the river in the Kruger Park was used for this purpose (Turpie and Joubert, 2001).

Using these methodologies, the net benefits derived from the products and services within the Letaba Catchment were estimated at R16 177 049. Averaging this over the 92 Mm^3 which represents the quantity of ecological water determined in the water balance, an average value of R0,19/m^3 is arrived at.

In considering the value of water in the Kruger Park, Turpie and Joubert derived a value for the whole of the Kruger Park water based on a travel cost methodology, as indicated in the first line of the table below. From this we have estimated that the contribution to these figures by water from the Letaba catchment is as given in the second line Once again an average value is calculated and presented in the third line.

	On-site expenditure	On-site and off-site expenditure	Consumer surplus
Whole of Kruger	R135 793 193	R266 626 926	R1 127 250 000
Letaba Catchment	R10 736 000	R21 081 000	R89 127 000
Value of water (R/m³)	R0.10	R0.20	R0.85

The table below summarises the characteristics of the current water use, showing water use, economic water price, costs and economic water value in each of the sectors researched in this study. The water price is the economic price as revealed by the water demand schedules at the given level of supply, i.e. the price which would be current if there were a market for water. The water value is the difference between the water price and its associated costs.

	Water Used Mm^3	Water Price R/m^3	Costs R/m^3	Water Value R/m^3
Agriculture	150.9	0.97	0.109	0.86
Forestry	36.3			
Pine	14.8	0.66	0.0083	0.65
Gum	21.5	0.27	0.0083	0.26
Municipal	25.4	5.72	3.5	2.22
Ecological	92.0	0.19	0	0.19
Kruger Park	92	0.85*	0	0.85

* includes consumer surplus.

Scenarios

Various water allocation scenarios were postulated to test the strength of the NSP model as an allocating mechanism. Three allocations will be presented, and their findings highlighted. The implications implicit in the findings will then be discussed.

Scenario: Current Allocation (Status Quo)

This scenario examines the current water allocations. The table below gives details of the allocated quantities, together with prices, values and an allocation benchmark. The water price is the price as defined above, but the water value is the value arising from consideration of the consumers surplus accruing in the relevant sector as a result of taking the allocated water quantity. This approach takes effects of the price elasticity of demand into account, and, consequently, the water value is much larger than the value derived in Section 1.4.2 above, in each case being larger rather than smaller than the price. The benchmark gives a measure of the total consumers surplus associated with this scenario.

	Allocation Mm^3	Water Price R/m^3	Water Value R/m^3
Agriculture	150.9	0.97	1.59
Forestry			
Pine	14.8	0.66	0.69
Gum	21.5	0.27	0.34
Municipal	25.4	5.72	7.35
Ecological	92.0	0.19	O.19
		Benchmark	**310.45**

Scenario: Reallocate Agricultural to Municipal

This scenario examines the effect of reallocating 5 Mm^3 water from agriculture to municipal. The comments are the same as for the preceding scenario with the additional observation that the benchmark has increased over that associated with the status quo. This indicates a larger consumers surplus and consequently a more effective allocation from the point of view of increasing social welfare.

	Allocation Mm^3	Water Price R/m^3	Water Value R/m^3
Agriculture	145.9	1.05	1.63
Forestry	36.3		
Pine	14.8	0.66	0.69
Gum	21.5	0.27	0.34
Municipal	29.9	3.76	6.17
Ecological	92.0	0.19	0.19
		Benchmark	**311.32**

Use New Unallocated Water

This scenario examines the use of allocating new and currently unused water. This situation could arise as a result of savings due to more effective demand management, better loss control, or development of new water resources. An increase of 5% in each sector is allowed for. Once again, comments are the same as for the preceding scenario, and it will be noted that prices have fallen and value has increased. The benchmark is the largest of the three scenarios.

	Allocation Mm^3	Water Price R/m^3	Water Value R/m^3
Agriculture	166.0	0.71	1.47
Forestry	36.3		0.68
Pine	16.2	0.64	0.68
Gum	23.7	0.25	0.33
Municipal	27.9	4.65	06.69
Ecological	92.0	0.19	0.19
		Benchmark	**327.30**

Implications of Scenarios

A hypothesis to be tested was that "water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques". This has been effected by subjecting the model to a series of scenarios designed to test its capabilities over a range of inputs, some of which are described above. It was found to allocate water effectively and consistently according to the principle of maximisation of net social profit. This can be seen by the fact that the benchmark varies and prices and values rise and fall in an appropriate manner. It was also found that the model would not allocate a greater quantity of water than that associated with the market clearing price which occurred at the intersection of the demand and supply schedules. This is due to the fact that the area of the consumers surplus beyond the clearing price becomes negative, and including it reduces the overall consumers surplus. This is consistent with the fact that economic theory holds that the market clearing price is the most economically efficient price. This means in practice that as the market clearing price for each sector reaches its clearing price, the rate of increase of the consumers surplus would decrease, until such stage as all clearing prices have been passed, when no further increase in the consumers surplus will occur. At this stage any further increases in allocation will not improve the benchmark. It should be noted that if this condition occurs, then it is likely that the supply and demand schedules are no longer relevant to these allocations, and the schedules should be revised.

It must again be emphasised that, as the model stands, the figures quoted are relative figures, covering a range of values with various levels of errors. The model should therefore be used to indicate broad trends only to guide policy formation and ought not to be used for detailed policy decisions. The use of the model will, however, indicate the direction which water markets might take if they could be implemented.

CONCLUSIONS

The literature surveyed gives support to our initial hypotheses and provides encouragement for proceeding with our chosen methodology. The literature on water accounts emphasise the need for proper water accounting to provide a sound basis for allocating water to various sectors. The use of Contingent Valuation for valuing municipal water and the use of linear programming for deriving water demand schedules from enterprise budgets is also well supported.

Following the above-mentioned modelling approach, it proved possible to produce a suite of models which enable water demand curves to be generated for the four water-using sectors covered by this study. In addition, means were provided to integrate these results and to explore and benchmark water-use scenarios by allocating water according to the principle of maximisation of net social payoff used in this study as a proxy for social welfare.

This has effectively addressed hypothesis two to four stated in the introduction to this study, which stat in essence that:

- Water demand can be synthesised using contingent valuation techniques, linear programming and crop production function; and
- Water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques.

As far as consideration of the water balance is concerned (objective one), it proved possible to compile acceptable water resource accounts for the Letaba River Catchment. It should be noted that the emphasis was placed on the construction of the water balance framework and not other aspects of water resource accounting such as asset accounts.

The linear programming approach used in this study to develop water demand schedules for agricultural water use has provided schedules which are consistent with existing norms which delivers results consistent with other exercises in this field. Some detail is lost in linearising the schedules, but this is necessary in order to be able to present them to the NSP model and it also provides some smoothing of the intrinsically lumpy curves. The linear program was successful in deriving water demand schedules for individual crops as well as for aggregated agriculture.

Although great difficulty was experienced in obtaining suitable data for water production functions for forestry, the latest enterprise budgets (2002) were available from Forestry Economic Services and these budgets form the underpinning of the exercise. As in the case of agriculture, the water demand schedules have been linearised to enable them to be smoothed and carried forward into the NSP model.

The Contingent Valuation Survey in this study, utilizing the one-pass approach, proved to be an effective approach for determining the economic value of municipal water. Comparisons made between the results of this study and previous studies locally and internationally give confidence in both the methodology and the results. Furthermore, the data in the CV Survey for this study reveals no outliers which significantly influence the results. The derived demand schedules are consistent with economic theory.

In brief it can be said that the objectives of the study have been met and that the hypotheses put forward have been proved.

However, some caution needs to be exercised when interpreting the results provided by this study. This comment need not detract from the value of the study, but it rather emphasises the need for understanding of the underlying principles and strengths and weaknesses of the models when using their results.

RECOMMENDATIONS

Having explored the various models discussed in this study and verified their operation, it is considered that much useful work could still be done in this field to remedy many of the shortcomings of this study. The following approaches are recommended:

- Attempts should be made to delinearise the linear programming models (including the agricultural and Net Social Profit models) by using non-linear objective functions.
- This includes that adequate data sources are crucial for further research. Work should be done on identifying and assembling more accurate and appropriate data.
- The models do not necessarily need to be more robust – they have performed satisfactorily within their limitations in this study, but they would be more effective if used in a more focussed manner. This would mean using them on a more restricted data-set where attention could be paid to improving accuracy in a more restricted environment.

ACKNOWLEDGEMENTS

A number of people made important contributions to this study by sharing their experience, knowledge, advice and encouragement with the author. It is therefore appropriate to thank the following persons who contributed indirectly or directly to the completion of this study.

The Steering Committee:

Dr GR Backeberg	Water Research Commission (Chairman)
Mr CJ Williams	Economic Project Evaluation (Project Leader)
Mr GA Veck	Economic Project Evaluation
Mr MR Bill	Economic Project Evaluation
Mr LJ van Rooyen	Letaba Water User's Association
Mr JL Van Zyl	Forestry SA
Prof HD van Schalkwyk	University of the Free State
Dr M Shaker	Limpopo Department of Agriculture
Dr N Reynolds	Earth Africa
Mr NJ van Wyk	Department of Water Affairs and Forestry (NWRS)
Dr ME Ligthelm	Department of Water Affairs and Forestry (Mpumalanga)
Mr MK Angliss	Limpopo Environment Affairs
Mr HJ Badenhorst	Tzaneen Local Government
Dr S Freitag	SA National Parks

The financing of this project by the Water Research Commission and the contributions of the members of the Steering Committee is gratefully acknowledged.

This project was only possible with the cooperation of many individuals and institutions. In particular, the work performed by Mr William Mullins is acknowledged. This study could not have been accomplished without his practical knowledge of agriculture and his constructive comments, diligence and enthusiasm with respect to the data collection in the field. The contribution of Mr Schalk van Vuuren and his team from MSSA for performing the Contingent Valuation Experiment in Polokwane is also gratefully acknowledged.

The authors also wish to record their sincere thanks to the following project team members who assisted and contributed in the research process by identifying study areas, developing the different questionnaires, and assisting with exercising the various models:

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Tebogo Kgoale	University of Venda student
Lefentse Nokaneng	Economics graduate in training
Liza Ueckermann	Economics graduate in training
David Mosaka	Mosaka Economic Consultants

LIST OF ACRONYMS

CVM	Contingent valuation methodology
DWAF	Department of Water Affairs and Forestry
EPE	Economic Project Evaluation (Pty) Ltd
GFI	Gross farm income
LP	Linear programme
MAI	Mean annual increment
MAP	Mean annual precipitation
MAR	Mean annual run-off
NFI	Net farm income
NI	Net income
NSP	Net Social Profit
SAAGA	South African Avocado Growers Association
SABGA	South African Banana Growers Association
WRC	Water Research Commission
WSM	Water System Management (Pty) Ltd
WTP	Willingness-to-pay
WUA	Water Users Association
Mm^3	Million cubic metres
10^6 m^3	Million cubic metres

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 INTRODUCTION

This Chapter is divided into seven sections not including this introduction. The first section explains the rationale and objectives of the study; the second sections sets out the hypotheses to be tested by the research; the third section provides some background to the study area; the fourth section sets out the research methodology; the fifth section discusses data required and its availability; and the last section provides an overview of the schema of this report.

1.2 RATIONALE AND OBJECTIVES

Nieuwoudt et al. states "As South Africa is a drought-prone, water poor region it seems probable that water shortages will redirect economic development. As water scarcity increases, the need to manage water as a national asset and for overall social benefit becomes imperative. During the past number of years the South African Water Research Commission initiated a number of economic research projects aimed at determining the value of water in different sectors of the economy and in different parts of the country."

This project is one of those initiatives and it explores the value of water as an economic resource in the Groot, Middle and Klein Letaba river catchments.

The aims and objectives of the study are to:

i Determine the water balance in the catchment; taking into account the confluence of the Klein, Middle and Groot Letaba;

ii Determine the water demand schedules for the irrigated agriculture, forestry, eco-systems and household sectors;

iii Use these demand schedules to determine the economic value[2] of water by establishing willingness-to-pay;

iv Determine the supply schedules for the same sectors in order to compare the cost of water with its value; and

v Generate water use scenarios and evaluate their impact.

1.3 HYPOTHESES

The following four hypotheses underpin the research described in this report:

i) *It is necessary to research the value of water because*

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2 When we consider the value of water in this study, it is always the economic value which is being referred to. The economic value encompasses the complete value of water to the economy, not just the infrastructural costs associated with making water available to end users. In essence, it also incorporates the "value of the water drop"; the value of water itself as a resource.

- water is scarce,
- South Africa's water laws have recently changed, and
- knowledge of the value of water can assist with allocation decisions.

ii) *The value of water is embodied in the user's willingness to pay, which is revealed by the consumer surplus associated water demand schedules associated with different uses of water, where*

- water demand may be direct (i.e. municipal and ecological usage), or
- derived (i.e. industrial, agricultural and forestry usage.

iii) *Water demand schedules can be synthesised using*

- Contingent Valuation techniques for direct demand situations, and
- Linear Programming and Crop Production Functions for derived demand situations.

iv) *Water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques.*

1.4 STUDY AREA

The Letaba water management area lies entirely within the Limpopo Province and forms an integral part of the Limpopo Basin. The study area comprises the Groot, Klein and Middle Letaba catchments. The Groot Letaba area forms part of the Lowveld Region of the Limpopo Province and represents the heart of the provincial economy, whilst the Klein and Middle Letaba can be classified as rural with a strong bias towards agriculture and retail.

Ample scope is provided in the catchment for research into the four key water users set out under section ii of the aims and objectives above.

1.5 RESEARCH METHODOLOGY

The value of an economic good can be approximated by a measure of users' willingness-to-pay to have the good rather than go without it. This value can be expressed in terms of the money that can be exchanged for the commodity provided an explicit market for it exists. Hence, if it is possible to estimate a market demand curve, the value of a good may be approximated as willingness-to-pay by measuring consumer surplus.

These water demand curves will be synthesised through the use of various modelling techniques. The approach employed is to use contingent valuation methods for direct demand and enterprise budgets and linear programming or enterprise budgets with crop water production functions for derived demand. For scenario evaluation a model which allocates water according to the principle of maximisation of social welfare is used.

The output of the models is water demand schedules for different water user groups from which consumer surplus and water value are imputed. The scenario evaluation model reallocates water and sets appropriate prices as well as provides a benchmark which indicates the extent to which the welfare-maximising objective of the exercise is met.

1.6 DATA

In order to effectively model water demand curves, it is essential to be able to locate data which relates production or user utility with the quantity of water used. In the areas of forestry and agriculture, such data is extremely difficult to come by. Research and data gathering performed by various Growers Associations, Forestry Economic Services and key farmers in the area provided a data set which enabled water demand curves for agriculture and forestry to be synthesised. Contingent valuation experiments in the field were used to establish willingness-to-pay amongst municipal water users. In the area of ecological water, data which reacted to different levels of availability could not be reliably established, so demand curves could not be constructed, but a single value for water related to the current availability of ecological water was established.

There have been substantial increases in some inputs to the enterprise budgets between 2002, which is the base date of this report, and 2004. More specifically, these refer to increases in electricity and the effects of the introduction of basic minimum wages for farm workers. Whilst such changes cannot be incorporated into this study as they lie beyond our base date, it is of importance that readers be aware of his situation lest they be tempted to impute results and conclusions reached here to the present without due care and consideration.

1.7 STRUCTURE OF THE REPORT

This report is divided into eleven chapters, including this chapter., Chapter 2 provides a literature overview. Chapter 3 sets out the modelling techniques used and their associated models. Chapter 4 describes the demographics, water resources, water utilisation and socio-economics of the study area, and Chapter 5 investigates the water balance. In Chapters 6, 7, 8 and 9 the construction of the water demand curves and determination of associated costs takes place for agricultural water, forestry water, municipal water and ecological water respectively. In Chapter 10 various scenarios are proposed and an integrating model is used to explore allocating water under the principle of maximisation of social welfare. Chapter 11 brings the work to a conclusion by providing a summary of the objectives, results and conclusions of the study and recommendations for future work.

A list of selected references is provided, and, in addition, a set of Appendices embodying more of the technical background and detailed results form part of the report.

2 LITERATURE REVIEW

As stated in chapter 1, the general hypotheses upon which this study is based is as follows:

It is necessary to research the value of water because:

- water is scarce,
- South Africa's water laws have recently changed, and
- knowledge of the value of water can assist with allocation decisions.

The value of water is embodied in the user's willingness to pay, which is revealed by the consumer surplus associated water demand schedules associated with different uses of water

- water demand may be direct (i.e. municipal and ecological usage), or
- derived (i.e. industrial, agricultural and forestry usage.

Water demand schedules can be synthesised using

- Contingent Valuation techniques for direct demand situations, and
- Linear Programming and Crop Production Functions for derived demand situations.

Water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques.

This chapter provides an overview of the international and South African literature that specifically relates to the water valuation concepts and principles embodied in the above hypotheses. As such, it is a relatively limited survey of the extensive body of literature that deals with the subject of valuing water. Readers wishing to gain a broader overview of this subject are referred to the work undertaken by Louw (2002).

2.1 WATER IS A SCARCE RESOURCE

According to Louw (2002) "water resource management throughout the world is looming as one of the most important political, social, and economic issues of this century". Whilst water allocation and water quality will always remain as important water management issues, growing, changing social demands for available water, changing technologies and outdated laws and institutions for water allocation are combining to create new challenges for economists in determining the value of water.

In the introduction to their article, Nieuwoudt et al. state that: "As South Africa is a drought-prone, water poor region, it seems probable that water shortages will redirect economic development. As water scarcity increases, the need to manage water as a national asset and for overall social benefit becomes imperative".

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

2.2 SOUTH AFRICA'S NEW WATER ACT

Thompson (2002) states that it seems that naturally flowing and running water is *res omnium communes* in South Africa. The water belongs to no one in particular but to all, and those in need thereof could obtain rights to use it, with the State having the responsibility to allocate and regulate these rights in the public interest. This principle allows trading of rights to use water on a market as a mechanism in order to achieve efficient and equitable water utilization.

2.1.1 Water Rights

Under previous legislation, rights to water were based upon the location of the water resource in relation to land for certain purposes (the so-called riparian principle), although various mechanisms were in place to provide access to water for non-riparian owners. Trading of rights to water was possible, although the high transaction costs, lack of an effective institutional framework and policy statements resulted in the fact that market trades were rare. In areas where institutional structures were in place, such as a regulatory body and infrastructure like storage dams and distribution canals, markets developed and functioned more effectively after 1993 than in areas where these lacked. Further, the more a water resource was under stress, the bigger the chance was for a market to come into being. Even in areas where water resources were not under stress and nearly no institutional structures were in place, some form of trade took place. If there was a need for water, "a farmer (as a buyer or a seller) always made a plan".

The new national water policy and the National Water Act of 1998 brought about a new framework to water resource management. The riparian principle does not apply anymore and instead the framework is now to allocate water to achieve the "best possible use" of water. This involves more than productive use of water as it is necessary to weigh up social, economic and environmental objectives to achieve equity, efficiency and sustainability. Preference will be given to basic human needs and to protection of ecosystems and to international obligations.

Water allocations will no longer be permanent, but will be granted for a five year cycle with a maximum length of forty years. The allocations could be granted based on either the proportional or prior principles, or both. An allocation remains in force until the end of the period when it expires. The allocation could be suspended or withdrawn if there is non-compliance with the conditions of the authorisation. Allocations will be granted subject to a number of conditions and the guideline will be the criteria of "best possible use".

2.2.1 Water Licenses

All significant water uses will eventually be licensed. A process to register the uses, allowing water uses to take place under a system of general authorisations, inviting applications for licences to use water and evaluating these applications will be followed to achieve this. The invitation for applying for licences will be done in sequence of priority areas. Areas under water stress will generally be considered first.

Water uses that actually took place when the National Water Act of 1998 came into operation could be continued with, provided it was lawful when it took place. These uses will eventually be converted to licences, as part of the process of inviting applications for licences, if these uses are beneficial and in the public interest. Those persons who were entitled to use water under the legislation repealed by the National Water Act of 1998 but who did not exercised these rights, may not start to exercise these rights or for that matter trade those rights. These rights are not acknowledged in the new framework. If such a person wants to use water, the person has to obtain authorisation for that, just like any other newcomer, either by way of a general authorisation or a licence.

2.2.2 Trading Water-Use Allocations

The new framework allows for trading in water-use allocations. According to the policy, this will only be allowed in limited areas and will be subject to varying degrees of control depending on whether it is within a single-user sector or between different water user sectors and whether it is between water management areas. Attention will be given whether the equity objectives and fair resource allocations are achieved.

A water use is defined in the National Water Act of 1998 as the "taking of water from a water resource" and not the "using of the water". The "taking of the water from the water resource" should therefore be regulated as a water use and that use could be traded as a water use. On the other hand, a person who receives water supplied by a water services provider with a distribution system and who uses that water is not undertaking a "water use" and that could therefore not be regulated as a water use. It is the water services provider who takes the water from a water resource that undertakes a "water use".

The using of water received from a water services provider by way of a distribution system and the trading of that right should be regulated in terms of the conditions for provision of water services of the water services provider. If the services provider is a water user association, then it should be contained in the constitution of that association. The National Water Act of 1998 does not provide a framework if the services provider is the State. Agreements could be concluded to regulate the matter. The authorisation of the water services provider to take the water from the water resource could specify how the water should be distributed to the different persons receiving the water and how they should use it. The services provider should then incorporate these into the conditions for provisions of water services.

2.2.3 A right to Use Water

A right to use water, which is the basis of the new water policy and the National Water Act of 1998, is not ownership of property. However, it is submitted that water used by a person, irrespective of whether it is a "water use" as contemplated in section 21 of the National Water Act of 1998 or a "right to receive water from a water services provider in terms of the conditions for the provision of water services", is a property right or right in property as contemplated in section 25 of the Constitution (the property clause). The confiscation of the property without compensation (except if it is reasonable and justifiable in an open and democratic society based on human dignity, equality and freedom) is therefore also applicable to the water used while a person may be deprived from this water without compensation. If the effect of implementing the new water policy to achieve "best possible water use" results in that existing use of water is reallocated, then no compensation is payable for that. However, the National Water Act allows for paying of compensation in certain circumstances as far as water uses that actually took place when the National Water Act of 1998 came into operation are concerned.

2.2.4 Deprivation of a Right to Use Water

The Constitution permits a deprivation of a right to water which is imposed in accordance with a law of general application. Such a deprivation permits the regulation or reduction of water rights without compensation provided such deprivation or reduction is not arbitrary . Compensation is only payable in the case of an expropriation. Any taking of property which does not involve the transfer of rights and the acquisition of those rights by the expropriator or any other person is not an expropriation and does not carry with it an obligation to compensate.

Any taking or deprivation disguised not to be an expropriation to avoid compensation will be set aside on the basis of arbitrariness. The requirement of non-arbitrariness demands that any act of taking by the State should be carefully analysed to ascertain whether it "goes too far" so as to render it arbitrary, unreasonable or unjustifiable in an open and democratic society. In most cases such an analysis will only be possible on an *ad hoc* basis.

The provisions of the National Water Act are regulatory in nature. Whilst some of these provisions clearly provide for a deprivation and a reduction of rights, such as for the Reserve, they fall short of an expropriation of the rights and therefore do not create an obligation on the State to compensate for them. The taking away of rights without compensation of a right for the purpose of redressing past racial discrimination is not permitted unless it is reasonable and justifiable.

It may be reasonable and justifiable in an open and democratic society based on human dignity, equality and freedom not to acknowledging the rights of persons who were entitled to use water under the legislation repealed by the National Water Act of 1998, but who have not exercised these rights. Therefore this situation should attract no compensation. These persons have the right to apply for a licence to use water. Although the location of the water resources in relation to their land is in itself not a factor to be considered before a licence is issued, the location of the land has to be taken into consideration to determine whether a water use is the "best possible use" when it competes with a use further away from the water resource.

Although a "water use" and the right "to receive water from a water services provider" are only rights to use water and not ownership in water, these are vested rights in water. These rights are probably not secured in their attributes for various reasons, for example:

- As far as existing lawful water uses are concerned, the same problems of the previous framework experienced in interpreting and applying the principles of the repealed water legislation still apply to these uses and it is uncertain how and when these will be converted to licences;
- As far as rights in terms of a general authorisation made generally are concerned, these are probably made without considering the actual water available in a specific resource and whether it is the "best possible use" and may be revoked at any time;
- As far as rights in terms of licences are concerned, these are reviewed at least every five years and are for a period of not longer than forty years.

As all significant water uses will eventually be licensed, these rights could become more secure in there fundamental attributes, depending how the policy is implemented. Water rights could become more definable in terms of unit of measurement, reliability and priority of the right.

When an existing lawful water use is traded, a licence replaces the existing lawful water use. The existing lawful water use then loses the benefits it had as an existing lawful water use (for example the right to claim compensation) when the compulsory licensing process is applied.

There is an obligation on the Minister of Water Affairs and Forestry to establish a register of water uses, as part of a national water information system, that could facilitate the trading of rights to water. Other information necessary to determine the potential harm to third parties and the environment are also part of this information system. The Promotion of Access to Information Act(Act no. 2 of 2000) further provides a framework to requests for records of public bodies and private bodies.

The new framework severe the right to water from land and it is allocated to a specific person. The National Water Act of 1998 allows that this right could be transferred from the holder of the authorisation to another. A legal framework is in place to determine the potential harm to third parties and the environment so that the necessary steps could be taken to minimise this.

The new framework allows trading of a right to "take water from a water resource" and to "receive water from a water services provider in terms of the conditions for the provision of water services", although this is not absolute and may be limited so as to ensure that effective water resource management is enhanced.

2.3 USERS' WILLINGNESS-TO-PAY

If "economic benefits" are defined in terms of preference satisfaction or increased human welfare, the obvious question is how to measure such an abstract, ambiguous concept (Whittington, 1992). The notion of human welfare is a multidimensional concept that cannot in fact be measured directly. It is reasonable to believe that an individual's welfare increases if a sufficient supply of improved water is provided; if he or she is better nourished; or has fewer illnesses. It is unclear, however, what units one would use to measure "welfare". Instead of measuring human welfare directly, economists propose to transform it into a unit that can be measured on a single scale.

The unit suggested is money. Economists suggest measuring a person's change in welfare by the maximum amount of money income that an individual would be willing to give up in order to obtain an improvement. (For a change that reduces welfare, the proposal is to measure the amount of money that the individual would require in compensation in order to accept the change.) For example, consider an individual at an initial state of welfare (W_0) that he or she achieves with a money (and non-cash) income (Y) and a traditional water source. So:

$$\mathbf{W_0\ (Y_0, S_0).}$$

Suppose that an improved water system (SI) is proposed and that this new water system will increase the individual's welfare to W_1, then

$$\mathbf{W_1\ (Y_0, S_1).}$$

The economist would like to know how much this individual's welfare would increase if this new water system were installed, i.e. how large is W_1 minus W_0?

Since there is no reliable, accurate way to measure directly the individual's welfare in these two states directly, economists have proposed a different approach. One can try to determine the maximum amount of money the individual would be willing to pay (WTP) to have the new water system installed. In effect, the individual is asked to consider two combinations of income and water source that both yield the same level of welfare (W_0) : one in which personal income is reduced and the new water system is installed and another in which income is not reduced (i.e. stays the same) and the new water system is not installed (i.e. there is continued use of the traditional water source) :

$$\mathbf{W_0\ (Y_0 - WTP, S_1) = W_0\ (Y_0, S_0).}$$

In other words, the "rational" individual user is assumed to behave in such as way as to (or is asked to) adjust WTP to the point at which these two combinations of income and water source yield the same level of welfare. At this point, WTP is defined as the monetary *value* of the change in welfare, W_1 -W_{01} resulting from the installation of the improved water source. This monetary value of the change in welfare is defined as the "economic benefit" to the individual user of the new water system.

It is useful to consider two reasons why an individual would be willing to pay for an improved water system that offered the same *quality of water as the Individual's existing source.* If the quality is the same, the real costs of obtaining water from the new source (including any money price) must be less than for the existing source, otherwise the individual would" presumably choose not to use the new source. The first reason is that the individual will save money (or time or other costs) obtaining the amount of water he or she originally used from the existing source. This first component of the individual's willingness to pay is termed cost savings and may include not only monetary savings but also savings of time and other resources.

The second reason an individual would be willing to pay for the new source is that, because the water is now cheaper, he or she will generally decide to use more water. Of course the individual must pay for this increased water use, but perhaps not as much as the maximum amount he or she would be willing to pay. This second component of the individual's willingness to pay is termed the consumer surplus on the additional quantity of water used after the installation of the new water source. The two components of economic benefits are thus the cost savings on the quantity of water used and the consumer surplus on the additional amount of water used as a result of the installation of the new water system. It is important to note that the consumer surplus arises when the price of any quantity of water taken by the consumer is less than their willingness-to-pay and it thus provides a proxy for the economic value of the water once all costs have been taken into account. As such, the varying consumer surpluses which arise from different usages of water provide an allocation mechanism for scarce water. This does not suggest that the consumer surplus should be used to determine prices, but only that the relative sizes of consumer surpluses arising from different usages indicate the economic value of the water when so used. This concept is expanded and exploited in the methodology explained in Chapter 3.

It is important to note that these components of the economic benefits of additional water accrue *to the household,* not necessarily to society in general. If this additional water provided to the household must be taken from some other use where it has value (e.g. agriculture, industry), then from a social perspective there is an *opportunity cost* associated with providing this water to the household. In other words, the transfer of water has benefits to the household, but costs to the existing user.

2.4 THEORY AND PRACTICE OF NATURAL RESOURCE ACCOUNTING

The United Nations (1999) explains the relationship between the environment and national accounting as practised through the System of National Accounts (SNA) as follows in its manual:

"The need to account for the environment and the economy in an integrated way arises because of the crucial functions of the environment in economic performance and in the generation of human welfare. These functions include the provision of natural resources to production and consumption activities, waste absorption by environmental media and environmental services of life support and other human amenities.

Conventional national accounts have only partly accounted for these functions, focusing on market transactions and indicators that reflect important factors in welfare generation but they do not measure welfare itself. However, new scarcities of natural resources now threaten the sustained productivity of the economy, and economic production and consumption activities may impair environmental quality by overloading natural sinks with wastes and pollutants. By not accounting for the private and social costs of the use of natural resources and the degradation of the environment, conventional accounts may send wrong signals of progress to decision makers who may then set society on a non-sustainable development path."

According to Lange and Hassan (1999), National Resource Accounts, also known as environmental accounts or "green" accounts, are designed to correct the shortcomings of the SNA by including the following:

> **Measurement of wealth**. A country's wealth is critical in assessing its well being. The National Resource Accounts include all of a nation's "natural capital" (such as minerals, fisheries and wildlife) which is often not included at all or is only partly included, in the national accounts.
>
> **Consumption of wealth**. Well-being also depends on whether natural capital is being maintained for future generations, or is being depleted. The National Resource Accounts record the extraction of non-renewable assets like minerals or unsustainable harvests of renewable assets like forests as depletion of "natural capital". Consequently, National Resource Accounts provide more complete assessments of the rate at which assets are growing or being used up.
>
> **Dependence of economic activity on the environment**. The national accounts often do not record the use of natural resources like fuel wood or forest products which are essential to livelihoods but are not traded in the market. While some countries attempt to estimate the value of these essential goods, the coverage is usually incomplete in national accounts.

National Resource Accounts estimate these non-market resources and services:

> **Cost of environmental degradation and pollution**. The National Resource Accounts record the cost of degradation of natural capital resulting from economic activities like soil erosion, bush encroachment, or water pollution.
>
> **Environment protection expenditures**. Expenditures to prevent pollution and environmental degradation or to mitigate harm are not

explicitly identified or properly treated in the national accounts but are included in the National Resource Accounts.

National Resource Accounts assess the economic value of a country's natural resources and how they are used. They provide better measures of economic performance and link problems such as land degradation, groundwater depletion or deforestation to the economic activities that cause them, or are affected by them. This encourages policy makers to regard the nation's natural resources as capital assets rather than unlimited "free goods" and promotes sound economic decision-making. In the literature, three policy uses of National Resource Accounts have been mentioned (Asheim, 2000):

- Measurement of welfare equivalent income for the purpose of making comparisons over time (does an economy grow?) and across economies (which of two economies is better off?);
- Measurement of sustainable income for the purpose of judging whether actual development is sustainable; or
- Measurement of the desirability of policy changes.

2.4.1 International Developments Regarding Natural Resource Accounting

The SNA (Commission of the European Communities *et al*., 1993) is an internationally agreed framework for the systematic compilation and presentation of economic data for countries. It serves the needs of economic analysis, decision taking and policy making. These accounts can be compiled for successive time periods, providing information for the monitoring, analysis and evaluation of the performance of an economy over time.

Until quite recently, practically all countries omitted accounting for the environment from their national accounts. There were some good reasons for this omission. Firstly, human activity was perceived as unlikely to affect the environment so as to jeopardise its contribution to the economy and to wider human welfare beyond effects that were local and reversible. Secondly, accounting for the environment's contribution to the economy and human welfare was considered to be extremely difficult and complex, requiring the resolution of intractable methodological problems and the costly generation of a large amount of data. As a result, little or no action was taken to include the environment in the national accounts.

However, realities and perceptions change. It is now clear that human activities can profoundly affect, and are profoundly affected by, basic environmental systems and functions with significant implications for national economies and humanity as a whole. It has also become evident that all countries at different stages of economic development have experienced environmental depletion and degradation.

Yet without systematic, quantitative and structured relationships between the environment and the economy, it is hard to know not only what the various economic causes of environmental damage are, but also how such damage might be remedied. It is therefore not surprising that the inclusion of the environment in the SNA became regarded as a necessity. The difficulties of such inclusion became a problem to be solved rather than an insurmountable obstacle.

The revised System of National Accounts (1993) for the first time explicitly included natural resources in its balance sheet and accumulation accounts, and introduced environmental accounting in a satellite accounting framework. Natural assets such as land, subsoil assets and uncultivated forests are included in the balance sheet provided that institutional units (households, government units, corporations and non-profit organisations) exercise effective ownership over these assets and draw economic benefits from them.

National Resource Accounts are currently constructed by a number of industrialised countries, including Norway, Sweden, the Netherlands, Japan, Germany, France, Italy and the UK. Some developing countries are institutionalising the construction of national resource accounts, including the Philippines, Indonesia, Korea, Mexico, Colombia, Costa Rica, as well as Namibia, Botswana, and South Africa. Many other countries have constructed National Resource Accounts on an experimental or intermittent basis.

2.4.2 Advantages of the Economic Accounting of Water Use

As already mentioned in the background to this document, water is probably one of the main natural resources affecting economic growth in the strongest economic regions of southern Africa. Water resource accounting for the country as well as for the region as a whole can thus be of great benefit in the effective management of water resources.

Water resource accounting can assist in answering the following questions:

What is the nature and magnitude of the economic value of water? This information is of considerable importance in the composition of national and regional budgets. Should water be of low value, such budget allocations will be made accordingly. On the other hand, in cases where the value of water is significant, proportionate allowances should be made. Water resource accounting also benefits the optimisation of water allocation to various economic sectors and sub-sectors.

What are the benefits and costs of existing patterns in water usage? This will enable the calculation of cross-subsidisation among different groups/sectors of water users.

What are the economic costs of the degradation or depletion of water resources, and what can be done about this?

How can water resource use be prioritised? What are the economic trade-offs among competing water users?

What changes in policy and technology can help the country achieve development objectives, given its scarce water resources?

2.5 ECONOMIC PRINCIPLES FOR VALUING WATER

In essence, water has two main uses: it is consumed directly as a consumption good or it is used as a factor of production in agriculture, forestry and industry. To provide a background to the review of tools used for the valuation of water, the economic foundation of both demands are briefly stated. It needs to be stated at the outset that at the time of writing, two similar studies on the value of water have already been published, *viz*. Louw (2002) and Conradie (2002). Both of these studies had extensive literature reviews exploring the same issues that are relevant to this study, and these works extensively underpin many comments and conclusions in this section.

2.5.1 Water as consumption good.

Municipal demand is the only category where water is consumed directly. Therefore, municipal water competes directly with other items in the household budget. As such, consumer choice can be modelled as utility maximisation, given a budget constraint, from which a downward sloping demand for water can be derived. This demand schedule can then yield the price elasticity of demand for water and consequently the value of the water.

According to economic theory the following variables affect the demand for a consumption good: the price of the good, prices of other goods, household income and wealth, sociological factors, household tastes and distribution of income.

From an empirical measurement perspective, total value of water for municipal use can be quantified by the consumer surplus (area under demand for water but above the water price). The marginal value for water (marginal utility), which is its scarcity value, is reflected by the price of water. A condition for economic efficiency in consumption is that marginal utility must be equated for all consumers which is achieved as all consumers in a given area face the same price for water.

It can be argued that this premise does not necessarily extend to water for basic-needs as, whilst poor consumers may be willing to pay an infinite amount for basic needs water, they may be unable to do so and so be excluded from the resource.

Several studies in poor communities have, however, indicated that poor people are willing to pay for water and that this willingness-to-pay indicates the opportunity for efficient allocation through price (Conradie, 2002). 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).

2.5.2 Water as an input of Production.

Theoretically the demand for irrigation water is a derived input demand as irrigation water is a factor of production. An input demand is derived from the demand of the product (profitability of crops, etc.), the production function (water plant efficiency), and the supply conditions of other factors of production (water saving technologies). The total income generated by the application of water (total value) can be measured by the integral of the area under the input demand function of water. The value of an additional unit of water can be expressed by the value of the marginal product.

Whether the total contribution or the marginal contribution is estimated in a study, depends on the technique used. In a crop budget, total cost is deducted from total income yielding the total and average contribution of water. Programming techniques can provide information on the Value of the Marginal Product (VMP) of water given by the shadow price of the water constrained, which is the marginal value. The latter technique can also be used to derive the total and average value of water. Production functions provide information on the VMP of water although average value can also be derived. The willingness-to-Pay (WTP) approach estimates average consumer surplus which is an approximation of market values and thus estimates marginal value.

2.6 TOOLS USED TO DETERMINE THE VALUE OF WATER

2.6.1 Market Value

The market price is what willing buyers and willing sellers agree on. The market price allows for the cost of risk and risk aversion, capitalisation rate of future income streams, the profitability of crops that will change from time to time, supply and demand factors, etc. The value of water depends very much on availability that may change or product prices that can change (fruit crops are exported and profits depend on the Rand exchange rate). Dynamic models can be used but they are blunt approximations that are out of date by the time they are completed. Risk is a major cost as Conradie (2002) showed that you could only attempt to measure. Her water estimates vary significantly with different assumed risk aversion values. The frontier on quantification of risk has moved further in this type of Operations Research models than in Econometric models but these models remain blunt (the senior author of this paper has conducted research on both these models in the USA during different sabbaticals).

2.6.2 Contingent Valuation

As stated by Veck and Bill (2000), an important factor in being able to manage metered water effectively is knowledge of its price elasticity of demand.

They further note that a method of research often used by economists to determine the values of goods which are not bought or sold in a market, is usually undertaken by simulating a market where respondents are asked in surveys how much they would pay for a commodity, or conversely, how much they would accept in return for a good of lesser quality. Responses to such questions are known as "Contingent Values" (CV) because they are values that respondents say they will pay, or receive, contingent upon a market being created. It is thus concluded that CV values are good surrogates for actual behaviour and that CV measures from surveys can be directly and validly compared with economic values attained from behaviours in the market place.

Veck and Bill (2000) further comment that "the CV approach is used to estimate values for environmental amenities and non-market goods by means of surveys. It was first suggested by Ciriancy-Wantrup (1952). In 1963 Davis applied the method to measuring the recreational value of woodlands in the state of Maine in the USA. In 1974 Randall Ives and Eastman established tile structure of the contingent market and suggested an Iterative bidding process for revaluing the preference of individuals for non-market goods. To deal with operational questions that arose in conducting studies, applications of CV experiments were greatly extended in the following years and the social-psychological aspects of CV experiments were researched."

The problem of estimating the price elasticity of demand for municipal water using contingent valuation methodology (CVM) were researched by Thomas & Syme (1988) and they concluded that water pricing is one of the most important economic instruments that is effective in controlling consumer demand for water.

Gramlich (1977), Daubert and Young (1981) and Greenley, Walsh and Young (1982) also provide evidence that CVM is effective in estimating the benefits of improved water quality and instream flow requirements for water recreation. CV is therefore gaining acceptance as a bona fide approach to the problems of water and human welfare.

Veck and Bill (2000) comment "In conclusion, it would be wise to step back from the debate surrounding whether CV experiments are acceptable or not in estimating the value of water and to concentrate on what has been accomplished by using the technique. In this respect, it can be argued from an examination of the literature on the subject that CV reveals that those who have set out to develop CVM and test its validity have made considerable progress in creating a tool that is useful for measuring non-market values. CVM has found ready acceptance by such agencies as the US Army Corps of Engineers, the US Fish and Wildlife Service and the US Environmental Protection Agency. In addition, the US Environmental Protection Agency, in its Guidelines for Performing Regulatory Impact Analysis published in 1983, listed CVM as one of four methods for valuing the environmental benefits of proposed regulation."

2.6.3 Mathematical Modelling Techniques

Mathematical modelling techniques can be used to explore many situations by simulating physical phenomena by means of mathematical models (linear programming is one such example). These techniques are very useful for analysing agricultural problems and are extremely flexible and can allow for different variables, such as, for example, soil types, different water saving technologies, fixed costs of irrigation investment and can incorporate portfolio risk. The following studies commissioned by the WRC used this technique: Conradie (2002) and Louw (2002). Future use of this technique could include more dynamic relationships. The approach used by the two studies is of interest as Louw (2002) used positive linear programming and Conradie (2002) used risk modelling (MOTAD).

2.6.4 Studies using farm linear programming approaches

There have been a number of applications of parametric linear programming to estimate the demand function for water in Australia. Flinn (1969) used a similar approach to that of Moore and Hedges (1963), by estimating the regional demand for water by aggregating the demand functions determined from five individual farm linear programming models. An important feature of Flinn's work was the estimation of intra-seasonal as well as seasonal demand functions. Flinn also pointed out that the shadow prices of institutional constraints imposed on a quadratic programming model of a river basin are generated in the same way as the opportunity cost of physical constraints, thus making it possible to compare the economic cost of administrative decisions with policies based on efficiency criteria alone.

Gisser (1970) used parametric linear programming to estimate demand functions for imported water as an alternative to depleting groundwater reserves in the Pecos River Basin in the USA.

Hamilton *et al.* (1989) examined the potential for using a market to shift water from irrigation to a hydropower user in periods of low river flow in the Snake River Basin of Idaho and their results support the hypothesis that the marginal value of water in irrigation is relatively low.

Jones, Musgrave and Bryant (1992) analysed water allocation scenarios and irrigation supply reliability in the Murrumbidgee Valley of the Murray Darling Basin. They used a hydrology simulation model to generate annual announced allocation percentages which were then fed into a deterministic linear programming model.

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

Tisdell (1996) used linear programming models to estimate demand for water, which maximise the net revenue from irrigated production subject to cropping patterns, availability of irrigable land and the distribution of water entitlements. He concluded that the current water charge in the New South

Wales-Queensland Border Rivers region is well below its long-term equilibrium prices.

Moore and Hedges (1963) applied static linear programming to estimating individual farm demand functions for differing farm sizes in California, USA. The individual farm demand relationships were then aggregated by means of weights based on the distribution of farm sizes in the study area. A regression equation was then fitted and the aggregate demand curve and elasticities of demand were estimated. Gisser (1970) used parametric linear programming to estimate demand functions for imported water, as an alternative to depleting groundwater reserves in the Pecos River Basin in the USA, Gisser was able to use these functions to calculate regional incomes from various price scenarios for imported water.

Tewari (2003) used regression to estimate the value of water in commercial forestry. The problem with the latter estimates is that the results can not be compared with other studies in this document as different values are estimated. Tewari (2003) used production functions to estimate the value of water before other costs have been paid while other studies used a residual approach.

2.7 CONCLUSIONS

The literature surveyed gives support to our initial hypotheses and provides encouragement for proceeding with the methodology put forward in Chapter 1. The literature on water accounts emphasises the need for proper water accounting to provide a sound basis for allocating water to various sectors. The use of Contingent Valuation for valuing municipal water and the use of linear programming for deriving water demand schedules from enterprise budgets is also well supported.

The next Chapter deals with the question of the modelling approach and how the various models can be most effectively applied to derive our water demand schedules.

3 MODELLING AND METHODOLOGIES

3.1 INTRODUCTION

Historically, decisions on the allocation and pricing of water in South Africa have been made with respect to legal and administrative criteria. Such an approach caused few conflicts amongst competing end-users of this water whilst water was in plentiful supply.

In recent years the growth in competition for this water has resulted in the need for water to be managed in the most economically efficient manner possible. This situation has required water managers to develop normative approaches to the allocation and pricing of water. Conflicts between competitors for the existing water resources of South Africa will doubtless continue into the future and politics, rather than economics, will probably be the final arbiter in resolving such conflicts. Solutions to these possible conflicting situations may, however, be significantly assisted and better choices concerning equilibrium allocation and pricing may come about via economic intervention into the problem.

Water is a good common to all and in South Africa it is controlled by the Department of Water Affairs and Forestry and various water boards. Consequently, the price of water is not yet being widely set by free competition amongst many buyers and sellers.

The value of an economic good can be approximated by a measure of users' willingness-to-pay to have the good rather than go without it. This value can be expressed in terms of the money that can be exchanged for the commodity, provided an explicit market for it exists. Hence, if it is possible to estimate a market demand curve, the value of a good may be approximated as willingness-to-pay by measuring consumer surplus.

In setting out to determine willingness-to-pay for water, cognisance needs to be taken of the fact that willingness-to-pay derives from differing sources amongst various water users. Amongst municipal users, for example, users are willing to pay for water according to the utility which they derive from the use of the water. This represents a direct demand. Commercial enterprises, on the other hand, who use water as an input in their production processes, will be willing to pay for water according to their ability to derive additional profit from its use. This represents a derived demand.

In this chapter, modelling techniques will be explored which are appropriate for simulating water demand schedules for both direct and derived demands and a suite of models will be proposed.

The approach which will be recommended is to use contingent valuation methods for direct demand, and enterprise budgets and linear programming or enterprise budgets with crop water production functions for derived demand. For scenario evaluation, a model which allocates water according to the principle of maximisation of social welfare will be used.

The output of the models will be water demand schedules for different water user groups, from which consumer surplus and water value are imputed. The scenario evaluation model will reallocate water and set appropriate prices, as well as providing a benchmark which will indicate the extent to which the welfare-maximising objective of the exercise is met.

3.2 PHILOSOPHY

3.2.1 Introduction

The basic principle underlying the approaches to modelling is captured in the second hypothesis around which this study is formulated, *viz*:

- The value of water is embodied in the user's willingness to pay, and is revealed by the consumer surplus associated with water demand schedules for different uses of water.

As mentioned above, it is recognised that water demand may be direct (i.e. municipal and ecological usage), or derived (i.e. industrial, agricultural and forestry usage) and suitable methodology is required to meet these two cases.

These issues will be explored in more detail below and the modelling approach to be associated with each water using sector will then be discussed.

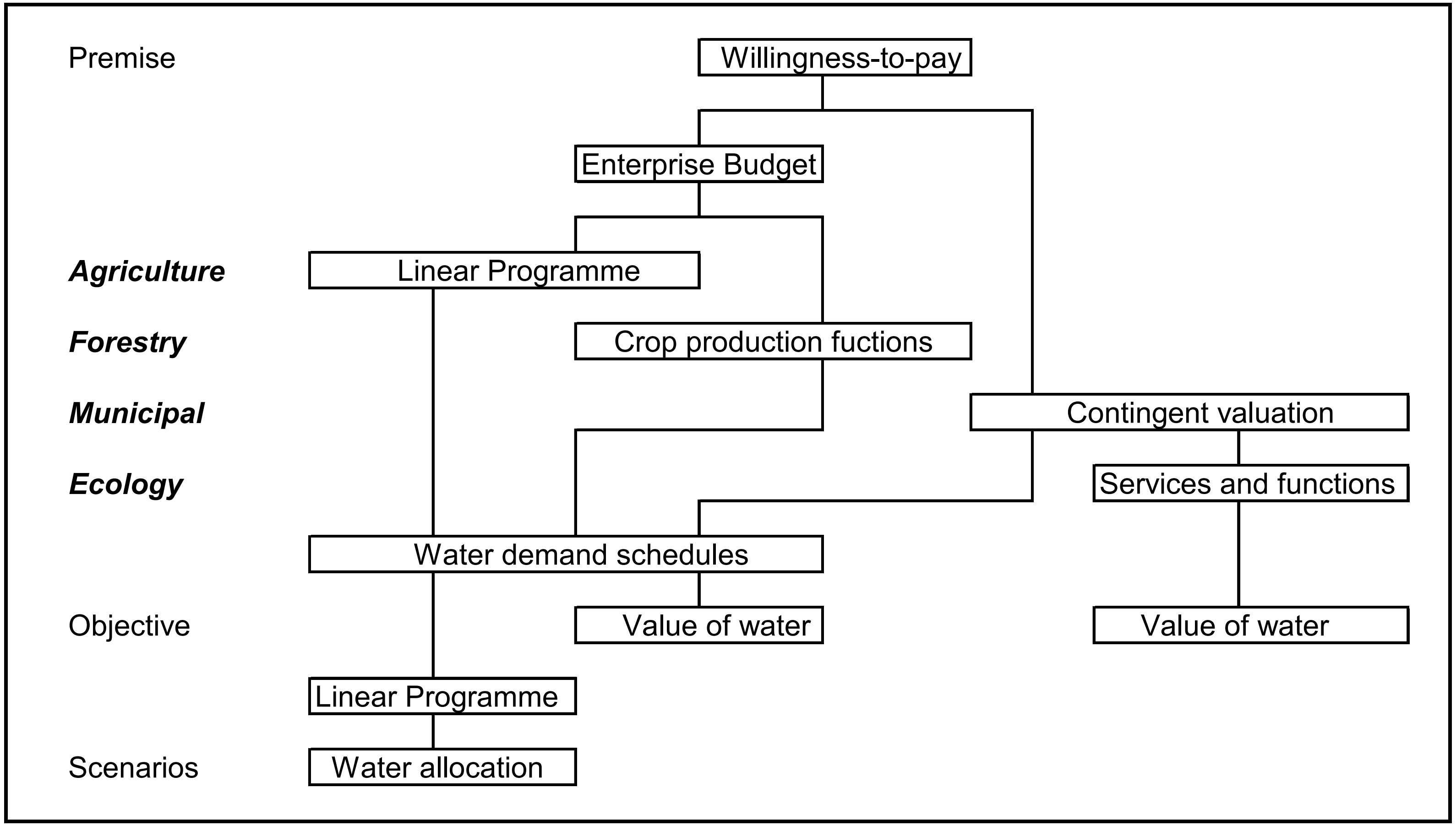
It should at the outset be emphasised that one of the objectives in this study was to present an approach to the valuation of water which was as transparent as possible, with the view of inculcating understanding in the reader, rather than to concentrate on results alone.

As a result, it was decided that the process would proceed through the use of a selection of models and modelling techniques with an integrating model as the final element.

3.2.2 Modelling Elements

A block diagram of the modelling process is presented in Figure 3-1, and this will serve as a framework around which the subsequent explanations and discussions of the various modelling elements will take place.

FIGURE 3-1: BLOCK DIAGRAM OF THE MODELLING PROCESS



Willingness-to-pay

Contingent Value Methodology (CVM) has been elected as the approach to be used in determining willingness-to-pay in the case of direct users of water. In social-psychological terms is a measure of behavioural intention in situations involving the buying of goods or services. Willingness-to-pay is used as an indicator of these intentions. Thomas and Syme (1988) have stated that CVM may provide a superior approach to other techniques for determining social, technical and behavioural responses to changes in the price of water.

However, farmers are not direct users and as yet there are few regular markets for water as such. Since irrigation water is not consumed directly, a direct measurement of its utility is not possible.

The utility of irrigation water is indirect as an input to production of other goods demanded by consumers. The willingness-to-pay for water would, therefore, depend upon the increased value of the output over and above the cost of producing that extra output. This concept is referred to as producer surplus. Kulshreshtha and Tewari (1991) have demonstrated that product supply curves can be used to produce derived water demand curves and that willingness-to-pay can still be obtained from these derived demand curves.

Enterprise budgets

When estimating the value of water which is subject to a derived demand, farm (or enterprise) crop budgets are an essential building block as they can be used to estimate the maximum revenue share of the water input to the production process. The total revenue derived from crops less non-water related input costs represents the maximum amount the farmer could pay for water and still cover costs of production. As such it represents the value of water at the current usage level. This value, divided by the total quantity of water used on the crop, determines a maximum average value of, or willingness-to-pay for, that quantity of water.

Linear Programming

Linear programming can be used to estimate marginal values for irrigation water on a representative farm. Water supply is varied and an LP solution is found for each quantity of water available to the farm, with all budget constraints adjusted to be consistent with the quantity of water used for each LP run. These constraints specify the combination of inputs and crops that will maximise net farm returns, including total irrigation water to be used in crop production. Two approaches for deriving water demand schedules for the farm are possible:

1. Average water values by crop are estimated by deriving a series of LP solutions for a range or water costs with all other constraints on the representative farm remaining static. The solutions specify the combination of inputs and crops that will maximise net farm returns, including total irrigation water to be used in crop production at each water cost. The set of solutions is a water demand schedule for the farm. (When it is assumed that each crop has a set irrigation water requirement for

cultivation and an all-or-nothing acreage, the LP demand schedule is a step-function with each horizontal segment representing a specific crop. As water costs go up, crops drop out of production one by one as they become uneconomic to produce. The water cost associated with each segment represents the maximum amount the farmer is willing to pay for water in producing that crop).

2. LP analysis can also be used to estimate marginal values for irrigation water on a representative farm (but not by crop). Instead of water cost, water supply is varied and an LP solution is found for each quantity of water available to the farm, all other constraints remaining constant. When the supply of water is low, the program solution allocates water to its highest-valued uses, but as supply increases, other less valuable or more water-intensive crops are added and the marginal value of additional units of water falls. The set of shadow prices derived at various levels of water supply is a water demand schedule for the farm.

Generally speaking, linear programming approaches will be found where it is possible to put forward a multi-crop representative farm where different crops have differing water-use efficiencies and crop substitution is feasible, as described above. However, it is also possible to use the technique with single crop farms (such as orchards or forests where crop substitution is not possible) if it is possible to demonstrate changes to the enterprise budget with changes in water used (in other words to demonstrate a range of water-use efficiencies for the same crop). This can be done if crop water production functions are available (as described below), or if orchards comprise trees of differing ages, where each age has a different water-use efficiency. In the latter case, separate enterprise budgets need to be compiled for each significant tree age on the farm. This approach has been favoured for the analysis of the value of agricultural water in this study.

Water Production Functions

In the absence of a suitable crop mix or selection of tree ages demonstrating differing water use efficiencies, crop water production functions (sometimes known as crop yield responses) will be required. These need to be non-linear (rising and convex) in order to produce a diminishing return to water. If profit is directly proportional to water usage then the demand schedule will be perfectly elastic. A decreasing marginal return to water usage needs to be demonstrated if there is to be a negatively sloping demand schedule.

In an appropriately constructed enterprise budget, this crop yield response is implicitly embodied in the budget variables for each water quantity. Explicit knowledge of the details of the crop yield response curve is not needed. If farm enterprise budgets do not implicitly incorporate this information, then an LP approach is not appropriate.

Crop water response functions are not readily come by, but if these exist for the relevant crops in an appropriate form (and if they enjoy sufficient credibility), then analysis of these functions will yield water demand schedules directly. This approach is that favoured in the case of forestry.

Of the approaches detailed above, the farm enterprise budget combined with linear programming is undoubtedly that most favoured (Nieuwoudt et al.). Its success depends mainly upon the availability of water sensitive enterprise budget, here obtained by considering orchards containing various ages of trees which display differing water use characteristics.

Contingent Valuation

In the past, the approach to valuing water and estimating its price elasticity of demand has been to use econometric modelling. The absence of convincing databases as well as difficulties with selecting explanatory variables and convincingly establishing them within a temporal framework has led researchers to explore the Contingent Valuation Methodology for this purpose. Noticeable amongst these efforts are the work of Veck and Bill (2000) in Alberton, Thomas and Syme (1988) in Australia and Hosking (2002), where CVM was used to establish the price elasticity of demand for water. CVM has also received considerable acceptance in the United States as a tool for measuring values to be used in benefit-cost analysis. The success of these researchers and an increasing acceptance of the methodology provide a compelling argument for also using it for synthesising water demand schedules for the purpose of estimating the value of water.

Scenario Evaluation and Water Allocation

For this purpose, a specific methodology was evolved to be used to analyse the economic consequences of allocating and pricing water at different levels in alternative uses in a particular water catchment or river system.

The basis for the model is an intersectoral equilibrium optimisation procedure wherein the allocation and pricing of regulated water supplies are such that the economic value of this water is maximised.

Under competitive market circumstances the market price for water would be equal to the marginal cost of supplying water to the market which in turn equals the value of the last unit of water used by different end-users, i.e. irrigators, industrialists and even home-owners. Economic theory suggests that in a catchment area or river system, a competitive market is necessary to maximise social welfare in relation to the available water.

As far as the suppliers of water are concerned, they are assumed in the model to allocate and price water in such a way that they are not profit maximising monopoly suppliers, but rather controlling bodies which endeavour to ensure that social welfare is maximised in relation to available water.

Generally the demand schedule for water should not include the full value of water at each point of use, but should be modified to take into account the costs of transporting the water to that point and also any treatment costs which may be required. The demand schedule is therefore hybrid.

The area under this schedule is what Samuelson (1980) termed the "Net Social Payoff". Takayama and Judge (1964) used quadratic programming to solve the Samuelson model using linear supply and demand schedules in price and quantity the maximand of which was the area between these schedules.

In the model developed here, linear supply and demand curves are used, but as long it is assumed that the demand schedules for water in its different uses are continuous, differentiable and intercept both the price and quantity axes of the demand schedule at definite values so that they are easily incorporated into the objective function of the model, they need not be linear.

In this way competitive water allocation and prices can still be achieved, so that if water suppliers agree to set the price for water to each class of customer equal to the marginal cost of servicing that customer and refrain from allocating and pricing water on the basis of non-market considerations, a quasi-market for water may be developed in South Africa.

3.3 THE MODELS

A brief précis of the modelling approaches used for each of the water-use sectors is given below. More details, together with the data used and the modus operandi of the models is given when the value of water for each sector is discussed in Chapters 6, 7, 8 and 9.

3.3.1 Agriculture

In the Letaba catchment, the following crops were used to construct a representative farm for the area:

- Avocados;
- Mangoes;
- Bananas;
- Citrus; and
- Tomatoes.

The modelling was approached using farm crop budgets together with linear programming. Farm crop budgets were prepared for all crops, but in the case of avocados, bananas, citrus and mangoes individual budgets were prepared for trees of varying ages. This approach enabled water values for the individual crops to be determined in addition to the water value for aggregated agriculture.

The linear program was formulated as follows:

Maximise profit:

$$\Pi(h) = \sum_{n}^{i=1} (R_i h_i - Cf_i - Cv_i * h_i)$$

Subject to:

Land availability $\sum_{n}^{i=1} h_i \leq Ht$

Water availability $\sum_{n}^{i=1} w_i \leq Wt$

Land allocation $(h_{lo})_i \leq h_i \leq (h_{hi})_i$

Profit $\prod(h) \geq 0$

Where:

$\prod(h)$	=	total profit, a function of hectares
$H(t)$	=	total hectares available
$W(t)$	=	total water available
w_i	=	water use coefficient for crop i
h_i	=	hectares under crop i
$(h_{lo})_i$, $(h_{hi})_i$	=	lower and upper constraints of land allocation
R_i	=	revenue per crop, a function h_i
Cf_i	=	fixed costs per crop
Cv_i	=	variable costs per crop, a function of h_i

The linear programme was exercised by starting with a full allocation of water, progressively reducing this, and watching the shadow price of water generated by the linear programme each time the basis of the formulation changes.

These shadow prices were charted, and demonstrated the stepped water demand schedule typical of this type of application.

3.3.2 Forestry

In the case of forestry water, the modelling was approached using farm crop budgets together with crop water production functions. In this instance, data was not easily come by with the only available and reliable source of forestry budgets being Financial Analysis and Costs of Forestry Operations produced by Forestry Economic Services. Crop budgets were prepared for pine and gum and included all fixed and variable costs, including the return to land, to provide a budget incorporating farm gate costs and prices.

It did not prove possible to compile budgets which reflected the sensitivity of trees to changes in water availability, so use was made of crop water production functions based on work done by Dye and Smith (2003) in order to develop full demand schedules from the forestry budgets available.

This approach enabled marginal water demand schedules for the two timbers from which water values for forestry were determined.

3.3.3 Municipal

Municipal water demand is a direct demand – households use water according to the utility they derive from so doing. One of the most direct methods for arriving at its value is to research the perceptions of users as to its value and the CVM has proved to be a suitable approach in the past.

The CVM uses surveys to elicit from respondents their perceptions of the monetary value of non-market goods contingent upon the creation of a market or other means of payment. In determining the price elasticity of demand for water, both Veck and Bill (2000) and Thomas and Syme (1988) made use of a two-part survey; one survey being used to establish a water usage profile and the other to carry out the contingent valuation experiment. Building on the experience of previous researchers, it was decided in this study to make use of a single contingent valuation survey, both to streamline the exercise and to avoid unnecessary annoyance to respondents. As in the case of the work done by Veck and Bill (2000) and Thomas and Syme (1988), the CV survey sought to determine respondents' behavioural changes with regard to water use when faced with changes in price, rather than to elicit a direct response as to their perception of the value of water.

In order to provide a suitable spread of income levels (low, medium and upper), two towns were selected in the study area to stand as proxy for the whole population, *viz*. Giyani for low-income water users and Polokwane for middle and upper income users.

The execution of the CV experiment and the development of water demand schedules is discussed in detail in Chapter 8.

3.3.4 Ecology

The determination of the value of ecological water was approached by considering the services and products provided by water in the river to the communities who lived near and visited the river. To keep the exercise at a manageable proportion, one river reach was selected to be representative of the services and products throughout the study area. The value of these products and services was estimated using contingent valuation and hedonic pricing approaches.

Issues such as fishes, reeds, sedges, waste assimilation and waste dilution were considered when evaluating services and products.

At the same time it was recognised that ecological water flowing from the Letaba river catchment entered the Kruger National Park where its value could easily be in excess of its value to the inhabitants of the catchment. Although valuing water in the Kruger National Park did not lie within the remit of this study, it was nevertheless considered important to be aware of the value of water in the Park, as this forms such an important ecological unit in South Africa.

Researching the value of water in the Kruger Park took the form of analysing existing work done on the subject, without performing any additional field work by means of a desk study.

3.3.5 Integration and Scenario Evaluation

For the purpose of bringing together the demand and cost schedules developed for various water users, an integrating model which allocates water according to the principle of maximisation of social welfare is used. The model achieves this end by calculating the consumer surplus associated with each water demand schedule and using linear programming to reallocate water in such a way as to maximise the sum of the individual consumer surpluses, thereby maximising social welfare, or Net Social Payoff (NSP), as it is referred to by Samuelson.

The input data required to operate the model is as follows:

- Demand schedules for each of the economic sectors considered in the problem being analysed. Such schedules must be explicitly specified and point out the characteristics of the water demand over time. For example, a year since variations in climate and seasonal demands for both agriculture and industrial products can influence the demand for water in different economic sectors. As far as household water is concerned, the diurnal demand for water for lawn watering and domestic purposes are not uniform. It must be noted that whilst the demand schedules shown in the mathematical description of the model are linear, as mentioned already, this is not mandatory as any non-linear demand schedule can be dealt with by the model.

- Cost schedules which represent the marginal costs associated with the transportation of a unit of water from the supply source (reservoir, dam or river) to each economic sector under consideration.

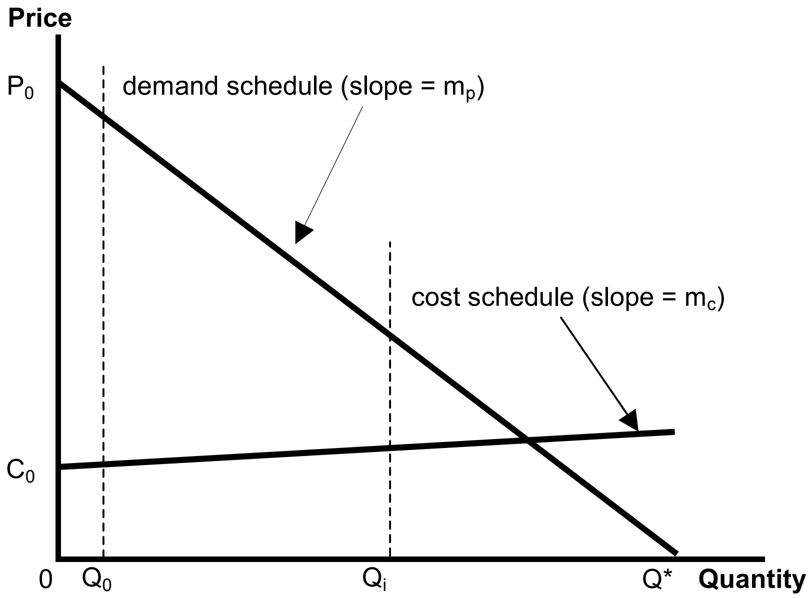
- Constraints presented by the physical characteristics of the water delivery system. The most important constraint is of course the actual amount of water available at any particular time; another is the design of the delivery systems which limits the amount of water supplied to any end-user at a particular time. Other constraints are needed to ensure the allocation of minimum quantities of water to sustain life and to prevent the collapse of critical enterprises.

The formulation of the problem is illustrated by the equation and diagram embodied in Figure 3-2 below. The NSP for each water use category is represented by the area bounded by the demand and cost schedules and the water quantity constraints Q_0 and Q_1. The equation specifies the aggregate of all the NSPs and also represents the objective function in the linear programme. When the linear programme is exercised, a water allocation Q1 is determined for each water use sector, and the associated value embodied in the water demand schedule is calculated. In addition, the value of the NSP is calculated to be used as a bench-mark against which the goodness of any one scenario can be evaluated vis-à-vis any other.

Different scenarios can then be generated by varying the constraints on availability of water to the various use sectors, and evaluated by the model.

FIGURE 3-2 ESSENTIALS OF THE NSP MODEL

$$NSP = \sum_{i=1}^{n} \left[(P_{0i} - C_{0i}) * (Q_i - Q_{0i}) + (mp_i/2 - mc_i/2) * (Q_i^2 - Q_{0i}^2) \right]$$



3.4 CONCLUSIONS

Following the approach outlined above, it was possible to produce a suite of models which enabled water demand curves to be generated for the four water-using sectors covered by this study. In addition, means were provided to integrate these results and to explore and benchmark water-use scenarios by allocating water according to the principle of maximisation of net social payoff, used in this study as a proxy for social welfare.

This addresses hypotheses three and four stated in the introduction to this study, *viz.*:

- Water demand can be synthesised using contingent valuation techniques, linear programming and crop production function; and
- Water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques and enabled these hypotheses to be tested.

The construction and exercising of the models for each water use sector will be described in more detail in the appropriate Chapters.

Chapter 4, which follows, provides a description of the study area to provide background and to give a framework in which the models will be exercised.

4 DESCRIPTION OF STUDY AREA

4.1 DEMOGRAPHICS

The Letaba water management area lies entirely within the Limpopo Province and forms an integral part of the Limpopo Basin. The study area comprises the Groot, Klein and Middle Letaba catchments. The Groot Letaba area forms part of the Lowveld Region of the Limpopo Province and represents the heart of the provincial economy, whilst the Klein and Middle Letaba can be classified as rural with a strong bias towards agriculture and retail. The Klein and Middle Letaba also have a significant agricultural potential in terms of the soil types and climate. This is confirmed by the fact that about 60-65% of total domestic tomato production is produced in the Mooketsi Valley. The only variable limiting the full development of this potential is the acute shortage of water. Due to the topography, rainfall varies from as high as 1 400 mm per year to as little as 200 mm per year.

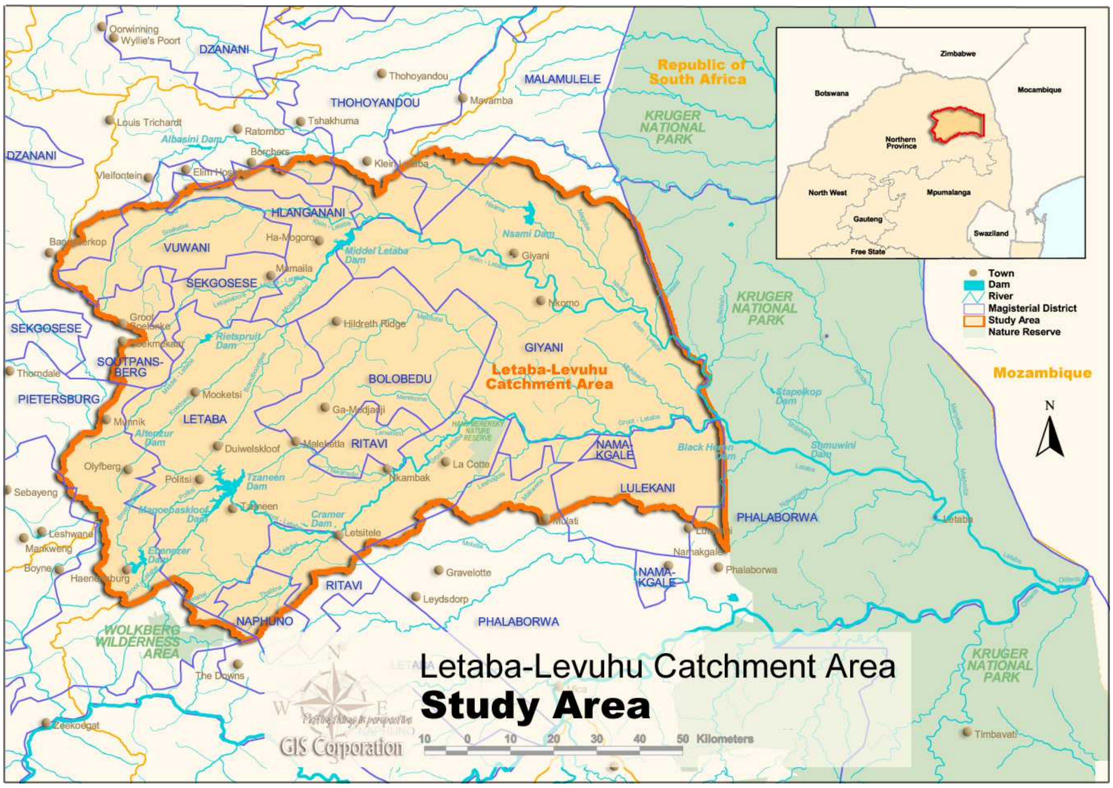
The Groot Letaba River is an international river with headwaters in the high rainfall, Drakensberg mountains, flowing through more arid areas and the Kruger National Park into Mozambique. At the border, in a dramatic gorge, it meets the Olifants River which flows into the large Massingir Dam in Mozambique. The main tributary of the Groot Letaba River is the Klein Letaba flowing from the north with a confluence just upstream of the Kruger National Park. An important feature of the catchment area of the Groot Letaba River is that afforestation and irrigation occur in the well watered western zone.

For purposes of this study, the following magisterial districts or their portion of were considered a part of the Letaba Water Management Area.

Malumulele
Soutpansberg
Thohoyandou
Vuwani
Bolobedu
Giyani
Hlanganani
Letaba
Lulekani
Namakgale
Naphuno
Phalaborwa
Ritari
Segosese

Important to note is that although Polokwane does not fall within the ambit of the study area, it was incorporated due to the fact that a major component of the primary water use is exported to Polokwane from Dap Naude Dam and Ebenaezer Dam annually. In a similar vein, although Malumulele, Soutpansberg and Thohoyandou are supplied from Levuhu, they are included in the ambit of this study as being part of the Letaba Levuhu Catchment.

FIGURE 4-1: MAP OF THE LETABA WATER MANAGEMENT AREA



4.2 WATER RESOURCES OF THE LETABA RIVER WUA

Changes in water demands in the Letaba River areas will ultimately result in the reallocation of water supplies between various user groups. Within the current water policy, specific water volumes must be supplied for primary users as well as for additional instream flow releases to secure a given level of ecological status.

The estimated natural Mean Annual Run-off (MAR) of the Letaba river area is (575 million m^3) and the ecological reserve is (105 million m^3). In Table 4-1 the breakdown in terms of both Mean Annual Run-off as well as Ecological Reserve for Letaba is given.

TABLE 4-1: NATURAL MEAN ANNUAL RUN-OFF AND ECOLOGICAL RESERVE IN YEAR 2000

Sub-Area	Natural MAR (million m^3/a)	Ecological Reserve (million m^3/a)
Groot Letaba	382	72
Klein Letaba	151	20
Lower Letaba	42	13
Total	**575**	**105**

The amount of surface water in the Letaba River area is 154 million m^3 and that of groundwater is 22 million m^3. The breakdown in terms of Natural resource composition is shown in Table 4-2.

TABLE 4-2: NATURAL RESOURCE IN THE YEAR 2000

Sub-Area	Surface Water (million m^3/a)	Ground Water (million m^3/a)
Groot Letaba	133	13
Klein Letaba	21	9
Lower Letaba	0	0
Total	**154**	**22**

Groundwater is extensively utilised and only limited potential for further development remains significant. Over-exploitation of groundwater occurs in parts of the study area, particularly near Albasini Dam in the vicinity of Thohoyandou.

Groundwater resources in the Groot Letaba River Catchment play an important role in:

- localised supplies for domestic use by small groups of people;
- stockwatering; and
- as a supplementary source for irrigation.

In essence, actual usable groundwater resources have not been successfully quantified and the degree to which this resource is already being used has been found to be a poor indicator of the actual availability due to factors such as

- paucity of data on actual abstractions;
- usage is intermittent and highly variable; and
- there is strong evidence of over abstraction or mining of resources in places.

Moderate to high groundwater potential is limited to very small areas in the Molototsi River Catchment and along the southern watershed with the Olifants River System.

Surface water mainly originates from the mountainous areas and is regulated by several dams in the upper and middle reaches of the river. The main storage units in the system are:

Dam Name	River	Storage capacity million m^3
Tzaneen	Groot Letaba	157.5
Ebenaezer	Groot Letaba	70.1
Dap Naudé	Houtbosloop	1.9
Magoebaskloof	Politsi	5.0
Hans Merensky	Ramadiepa	1.3
Modjadji	Molotsi	8.2
Thabina	Thabina	2.8
Majosi Dam		83.9
Nsami Dam		6.0
Crystal Fontein		117.8
Middle Letaba Dam	Sterk	184.2

It is significant that most existing major storage dams, except for Modjadji Dam and Thabina Dam are located in the small upper catchment of the Groot Letaba River.

4.3 WATER UTILIZATION

The assessment of actual water utilization in the Letaba River area has been reviewed from time to time, mainly for the following user sectors:

- Irrigation
- Primary use
  - in-catchment
  - exported to P
- Afforestation
- Ecological requirements

In Table 4-3 the breakdown of Water Requirements for the year 2000 is given.

TABLE 4-3: TOTAL WATER REQUIREMENTS FOR THE YEAR 2000 (MILLION M^3/A)

Sub-area	Irrigation	Urban	Rural	Afforestation	Total Requirement
Groot Letaba	126	4	10	35	175
Klein Letaba	25	3	8	1	37
Lower Letaba	0	0	0	0	0
Total	**151**	**7**	**18**	**36**	**212**

4.3.1 Irrigated Agriculture

Irrigated agriculture has long been established along the Letaba River area. Irrigated agriculture along the Groot Letaba River is highly developed in an institutional sense and in relation to irrigation equipment technology and management expertise. With regard to the Klein and Middle Letaba, the importance of irrigated agriculture cannot be under-estimated as it plays a crucial role in the livelihood of many people. It also serves as a large employment creator in the region.

As depicted in Table 4-4, the total irrigation requirement for the study area is 151 million m^3. The total irrigation requirement is distributed as follows:

TABLE 4-4: IRRIGATION WATER REQUIREMENTS FOR THE YEAR 2000 (MILLION M^3/A)

	Irrigation area (hectares)	Water requirement (million m^3/a)
Klein & Middle Letaba	4 452	25
Groot Letaba	14 379	126
Total	**18 831**	**151**

Important to note is the fact that with regard to the Groot Letaba, water requirements of 133 million m^3 was applied for purposes of this study. This figure was arrived at by considering the water requirements of the Groot Letaba in terms of the following climatic zones:

			Water requirement (million m^3)
*	Climatic zone 1	-	12.92 million m^3
*	Climatic zone 2	-	31.99 million m^3
*	Climatic zone 3	-	73.17 million m^3
*	Letsitele River	-	15.30 million m^3
			133.4 million m^3

It is important to note that irrigated agriculture is the mainstay of the local and regional economy.

Periods of water shortage for irrigation, of increasing frequency and severity have placed this sector under severe stress. Growth of irrigation led to the need for storage to stabilise water supplies while most of the irrigation area benefits from a regulated source. Run-of-river abstractions are the main sources along the Nwanedzi and Letsitele Rivers and to some extent along the Thabina River. In spite of major investments in storage dams and other water supply infrastructure, severe shortages still occur. The availability of water from storage for irrigation, for current levels of development, drops as low as 50% of full quota in some seasons with an average of about 85%. Availability of water in critical periods is much more significant than the average. Some run-of-river abstraction points have been completely dry in recent years.

It is important to note that periods of water shortage for irrigation can have a negative impact on the potential for further development in the Letaba area.

Shortages in this sector might arise due to the fact that in terms of the New Water Act 1998 (Act 36 of 1998), much emphasis is placed on primary water for human consumption as well as Instream Flow Releases to secure a given level of ecological status. To try to deal with these possible scenarios, various studies have been commissioned by the Department of Water Affairs and Forestry (DWAF) to look into how improved irrigation management strategies can be implemented in the Letaba and to look into the feasibility and viability of increasing dam walls for the Tzaneen dam to increase yield.

This studies include the Groot Letaba River Water Resources Development Feasibility Study conducted by EPE, Letaba River Dam Study conducted by Agrimodel, the Economic Evaluation of Water Storage Development in the Groot Letaba conducted by BKS as well as a Reconnaissance Study to augment the water Resources of the Klein and Middle Letaba River catchments conducted by WSM.

It is important that further resource development and intensified management should aim to check the deterioration of supplies and stabilise availability.

4.4 PRIMARY WATER CONSUMPTION

Estimates of primary water use are based on various levels of service for human consumption. The estimated population in the study area for the years 1991, 1995 and 2000 is indicated as follows:

	People in the Study area	Total gross primary requirements (million m^3 per annum)
1991	1 445 161	22.3
1995	1 583 392	24.4
2000	1 774 921	27.4

Important to note is that data was compiled for the time series, 1991-2000. In determining the population, the relevant magisterial districts that forms part of the Letaba Water Management area were considered. The study area is predominantly rural and it can also be mentioned that in the Groot Letaba as well as the Middle and Klein Letaba, 18% and 11% of the population reside in the urban areas respectively, whereas 82% and 89% reside in the rural areas. The population in the entire study area experience an annual growth rate of 2.3% per annum.

The average household size for the urban area for the high and middle income group is 4.85. Whereas with regard to the Rural area and low income category is 5.88.

With regard to this study, average primary consumption in the Groot Letaba, for the urban-rural dichotomy, is 55 and 30 litres per capita per day respectively. For the Klein and Middle Letaba, with regard to both urban and rural dichotomy, is 190 and 40 litres per capita per day respectively. The average primary consumption was assumed to be constant for the time-series due to unavailability or reliable data in this regard. However, the primary water consumption in the entire study area increases from 22.3 million m^3 in 1991 to 27.4 million m^3 in 2000.

A major component of the primary water use in the study area and with regard to the Groot Letaba in particular, is the 18.5 million m^3 per annum exported to Polokwane from Dap Naudé Dam and Ebenaezer in accordance with longstanding allocations and permits. This allocation is assumed to remain unchanged as Polokwane and environment have access to water supplies from elsewhere to meet increasing requirements.

It is also important to note that estimates of water requirements are fraught with uncertainties because of the diverse settlement patterns which occur in the study area. These range from long established, well developed urban areas like Tzaneen, to less developed urban areas like Nkowankowa, semi-urbanised communities and rural villages.

Social forces influencing settlement patterns and urbanisation are not well understood and the influence of aspects such as migration and infectious diseases further complicate the projections. Of considerable importance is the uncertainty associated with official population statistics and their interpretation in various previous studies.

4.4.1 Afforestation

The estimated use by the existing 49 300 ha of commercial forests is assumed to be the maximum permissible (i.e. no growth) and is not amenable to management intervention. The number of hectares under afforestation for the Groot Letaba as well as the Klein and Middle Letaba is 45 000 ha and 4 300 ha respectively. The total amount of water requirements in the study area for afforestation is 36 million m^3.

4.4.2 Ecological requirements

Recognition in the National Water Act 1998 (Act 36 of 1998) of a Reserve for purposes of satisfying basic human needs and for sustaining riverine ecosystems has a significant impact on the availability of water for other uses. The amount of water requirements with regard to Ecological Reserve in the Study Area is 105 million m^3.

Water availability for riverine ecosystems has in the past been neglected to the extent that the conservation status of some parts of the river system have been seriously degraded. This was estimated to be equivalent to between class D and class E as is currently defined.

To satisfy the estimated environmental requirements in the Groot Letaba area alone, 8 million m^3 on average per annum must be provided from storage in addition to the current allocation of 14.8 million m^3 per annum from Tzaneen. Furthermore a river maintenance flow of 61.5 million m^3 per annum at IFR3 in most years, suitably distributed through the season, and lowest drought flows of 12.8 million m^3 per annum in critical drought year is expected to return to the river to classification commensurate with the management objective set in the IFR assessment.

4.4.3 Transfers

Transfers-out from the study area occur with regard to the Groot Letaba and amounts to 11 million m^3. Important to note is that there are no transfers-in with regard to the entire study area.

4.4.4 Other Sectors

Interesting to note is that with regard to the Letaba study area, there exist no water requirements for mining and bulk industrial as well as for power generation. The reason simply being that these sectors are virtually non-existent in the study area.

4.5 SALIENT MACROECONOMIC INDICATORS IN STUDY AREA

4.5.1 Gross Geographic Product

A Gross Geographic Product (GGP) of R5 239 million was achieved in the year 2000. Important to note is that a considerable amount of GGP in the study area is based on the unproductive services sector which contributes in the region of 29% to GGP. Economic activity in the study area is mainly characterised by irrigation, afforestation, tourism and informal farming. The study area has a strong bias towards agriculture which serves as its financial resource base. Agriculture was responsible for 11.4% of GGP in the study area and 8% of the GGP in the Limpopo Province in year 2000. Other economic sectors in the study area are commerce (10%) and manufacturing (9.2%). It is important to note that most of the economic activity related to sectors such as manufacturing and trade takes place in the Groot Letaba.

Due to linkages, agriculture contributes significantly to trade, electricity, transport and finance sectors.

The GGP per capita in the study area stands at R2 952 and is considered the lowest of all provinces.

4.5.2 Employment

After community, social and personal services and wholesale, retail trade and catering and accommodation, agriculture and forestry is the highest employer in the study area. The informal employment sector in the study area relies heavily on agriculture and furthermore contributes 12% of the total number of people involved in the informal sector in the province. Unemployment rate in the study area is in the region of 47% and contributes only 14% of the unemployment rate in the Limpopo Province.

4.5.3 Household Income

With more than 309 000 households in the study area, the average household income for the high income category is R12 000 and R6 000 and below for the low income category. The study area contributes in the region of 11% of household income in the entire Limpopo Province.

4.6 CONCLUSIONS

The picture which emerges is of a region which is largely arid, which is mainly low income, but which has opportunities for commercial farming and forestry. The need for water is an important issue in every part of the region, and the need for effective water management is great. The ability to obtain economic values for water, and to use these for management decision support is clearly a matter of importance.

The next Chapter quantifies the water situation in the area by setting up a water balance through the medium of water accounts in order to understand how water is shared between the various water use sectors, and provides a basis for calculating aggregated water values.

5 WATER BALANCE

5.1 INTRODUCTION

Reconciliation of water consumption with available resources is an essential component of water resource management. This reconciliation needs to be done from a catchment level right up to the national level. A Water Balance Model can be structured to provide present and projected future supply-usage information on a consistent basis for a particular region or country and to match surpluses and deficits.

Knowledge of the water balance under any given set of circumstances is an essential component of water resource planning and management at a national, regional and catchment level. Its primary function is to assist planners and managers in the reconciliation of water supply against water usage. It also assists the investigation into ways in which the available resources can be used more efficiently in order to manage increasing demands and ensure that the resources are used in a fair and judicious manner. This reconciliation is in this instance done for the Letaba Catchment using a computational framework (here referred to as the water balance model) to identify and quantify all the water resources and the degree of utilisation of these resources. This model is a computational aid to assessing the balance between any given water supply and demand and should not be confused with hydrological models used to forecast water availability under different various climatic conditions. With regard to the Letaba catchment, the water balance model was used to identify areas of surplus and deficit for the period 1991 to 2000. However, the Water Balance Model in this catchment can also be used to provide information about supply and usage under projected future conditions, e.g. year 2010.

Of paramount importance is the fact that this model can also be applied to test various water management scenarios with regard to both supply and usage. It is also necessary to identify all the water users, the quantities of water used and the purpose for which the water is used.

5.2 WATER SUPPLY MODELLING

5.2.1 Mean Annual Run-off (MAR)

The study area is divided into quaternary and tertiary catchments. WRC (1990) provides estimates of mean annual run-off (MAR) under natural conditions down to quaternary sub-catchment level. Although few catchment are in a natural state, the natural MAR is indicative of the catchment's total surface water resource. Any activities that have reduced MAR should be categorised as water uses, e.g. forestation.

The only activity that can increase run-off in catchment is the paving of the surface associated with large-scale urbanisation. In essence the total water resource of a catchment can be defined as follows:

- natural MAR of catchment
- incremental urban run-off
- groundwater supply
- exploitable flow from upstream catchment
- Exploitable MAR by dams in catchment also called `Yield`.

According to WRC report no. 288/11/94 the mean annual run-off in the Groot Letaba is 381 Mm^3, and in the Klein and Middle Letaba it is 151.9 Mm^3.

5.2.2 Annual Run-off

For every catchment the area, evaporation, rainfall (MAP) and the MAP-MAR response can be determined. The MAP-MAR response is a relationship between mean annual precipitation and means annual run-off, which determines the actual run-off generated in a catchment.

If the annual rainfall in a region for a specific year is determined, this value is used to read from the MAP-MAR response graph the corresponding run-off. This run-off value is then multiplied with the area of the catchment. With regard to the Groot Letaba Catchment, the following calculation applies for average rainfall figures:

Catchment Area:	4 952 km^3
Annual Precipitation (AP):	684 mm
MAP-MAR Response:	5
Annual Run-off:	77 mm

$$\text{Annual Run-off} = \frac{4952 \times 77}{1000} = 381 \text{ million } m^3$$

For the Middle and Klein Letaba the calculations are:

Catchment Area:	5 453 km^3
Annual Precipitation (AP):	609 mm
MAP-MAR Response:	5
Annual Run-off:	28 mm

$$\text{Annual Run-off} = \frac{5453 \times 28}{1000} = 152.7 \text{ million } m^3$$

The correctness of this method is highly depended on reliable rainfall figures, catchment size and MAP-MAR response. Rainfall data are obtained from the South African Weather Bureau and allocated according to the MAP supplied by the WRC according to the correct catchment. The other data used in the above calculation was obtained from the Water Research Commission Report 298/3.1/94. It is important to note that this is not an absolute correct determination of the run-off as actual measurements are preferred, but the unavailability of data makes this method necessary.

5.2.3 Yield

Yield depends to a large extent on the development of a River. The manner in which yield calculations are performed depends on the classification of dams and some reservoirs.

According to DWAF (2003), the local yield in the Groot Letaba catchment was 160 million m³ for the year 2000. It was also expected to remain constant for the year 2023 base scenario given the existing infrastructure and recent development of infrastructure. It also includes return flows resulting from growth in requirements.

According to The Department of Water Affairs and Forestry's current National Water Resource Strategy Report, the local yield in the Klein and Middle Letaba catchment was 32 million m³ for the year 2000. It was also expected to remain constant for the year 2025 base scenario given the existing infrastructure and recent development of infrastructure (Nandoni Dam). It also includes return flows resulting from growth in requirements.

5.2.4 Evaporation

Surface Water Resources of South Africa 1990 (WRC Report No 298/1.1/94) provides a formula to determine evaporation. The formula is given in the following equation:

$E_v = 0.00066 \times E_n \times A_f$
E_v = volume of net evaporation loss (10^6 m³ pa)
E_n = Net Evaporation loss from reservoir (mm pa)
A_f = Area of reservoir surface (km²)

With regard to the Groot Letaba Catchment, Evaporation can be estimated as follows:

$$E_v = 0.00066 \times 1428 \times 18.6 = 17.53 \text{ Mm}^3$$

Important to note is the fact that with regard to the above figure, a significant amount of evaporation occurs at the Tzaneen Dam followed by the Ebenaezer Dam. However, small dams, most of which are built by farmers for irrigation, stock watering and other purposes also contribute to a lesser extend to the overall evaporation.

With regard to the Klein and Middle Letaba Catchment, evaporation can be estimated as follows using the method discussed for the Groot Letaba:

$$E_v = 0.00066 \times 1845 \times 25.63 = 31.21 \text{ Mm}^3$$

A significant amount of evaporation occurs at the major dams such Middle Letaba dam and Nsumi dam. However, small dams, most of which are built by farmers for irrigation, stock watering and other purposes also contribute to an extend to the overall evaporation.

5.2.5 Return Flows

Data on return flows was obtained from DWAF's current National Water Resource Strategy Report. The figure given for the entire Letaba for return flows is 16 Mm^3, this divided with 14 Mm^3 to the Groot Letaba and 2 Mm^3 to the Klein and Middle Letaba.

5.2.6 Transfers-in

Transfers-in do not take place with regard the catchment.

5.3 WATER DEMAND MODELLING

5.3.1 Water Use Classification

The different water use sectors for surface water are classified into six categories, as follows:

Households	A subdivision of household use between urban and rural was made. A split between outdoor and indoor use was also made with regard to both categories.
Industry	Use for this purpose entails industrial and commercial purposes mainly in urban environment.
Irrigation	For purposes of this study this category incorporates avocados, bananas, citrus and mangoes and tomatoes.
Afforestation	This use component has significant water consumption over and above the natural vegetation.
Ecology	Requirements to preserve the aquatic environment of the Letaba River System and supports a wide range of large and small animals in the Kruger National Park.
Transfers-Out	Although Polokwane does not fall within the Groot Letaba Catchment, it relies to a large extent from water transferred out of this catchment.

Endogenous Data Source

A detailed discussion of endogenous data sources and methods, per water use sector, follows below.

a) Households

- **Groot Letaba**
  In order to obtain a clear picture of water use with regard to this particular sector, rural and urban population trends, level of income as well as primary water use norms were established in the Letaba

Catchment. DBSA (1998) documents population figures per magisterial district. For purposes of this study, with the aid of a relevant map for the Letaba-Levuhu Catchment Area, only magisterial districts that fall within the Letaba were isolated in tandem with their respective population trends. These population trends are given for the year 1994 for both rural and urban areas. According to the same source, the population growth rate for both urban and rural in the study area is 2.31% per annum. A scenario was formulated whereby population trends in the relevant magisterial districts for the period 1991-2000 were determined using these growth rate.

In the Groot Letaba, urban-rural dichotomy stands at 18% and 82% respectively. According to Agrimodel (1997) the study entitled *Economic Evaluation of Water Storage Development in the Groot Letaba,* the annual per capita income of both urban and rural population is R7 914 and R1 284 respectively in 1995 prices. Currently annual per capita income of both urban and rural is R12 000 and R6 000 respectively. Water use norms per day per capita for both urban and rural population is 55 litres and 39 litres respectively. The average primary consumption was assumed to be constant for the time series considered due to unavailability of reliable data in this regard.

As can be deduced, there is a strong bias towards people residing in the rural areas relative to the total population in the study area. Given the adverse socio-economic conditions prevailing in the study area and the Limpopo Province in general, it was assumed that the majority of people belonging to the high-income category are based in urban areas.

Due to the fact that the study area is predominantly rural, it can also be assumed that most of the people classified in the low-income category are situated in rural areas. The average members per household for both urban and rural are 4.85 and 5.88 respectively according to the study on Economic Evaluation of water storage development in the Groot Letaba.

With regards to both urban and rural primary water use, a pattern of outdoor and indoor water use was determined. An assumption was made that for urban primary water use, the split between indoor and outdoor water use is 30% and 70% respectively. Regarding rural primary water use the split between indoor and outdoor use is 15% and 85% respectively.

A major component of the primary water use in the study area (with regard to the Groot Letaba in particular) is the 11 million m^3 per annum exported to Polokwane from Dap Naudé Dam and Ebenaezer Dam in accordance with long standing allocations and permits. This allocation is assumed to remain unchanged as Polokwane have access to water supplies from elsewhere to meet increasing requirements.

It is also important to note that estimates of water requirements are fraught with uncertainties because of the diverse settlement patterns which occur in the study area. These range from long established well-developed urban areas like Tzaneen to less developed urban areas like Nkowankowa, semi-urbanised communities and rural villages.

- **Klein and Middle Letaba**
  In the Klein and middle Letaba catchment area, urban-rural dichotomy stands at 11% and 89% respectively. Currently annual per capita income of urban and rural is R12 000 and R6 000 respectively. Primary water use norms per day per capita for both urban and rural population is 190 litres and 40 litres respectively were used. The average primary consumption was assumed to be constant for the time series considered due to unavailability of reliable data in this regard.

  Due to the fact that the study area is predominantly rural, it is assumed that most of the people classified in the low-income category are situated in rural areas. The average members per household for both urban and rural is 4.85 and 5.88 respectively.

b) Industry and other

The Groot Letaba region has a strong bias towards agriculture and the industrial sector is less significant. However, there is some economic activity with regard to the industrial sector.

Data for industrial water use was obtained from DWAF (2001). Total water use with regard to this sector is 0.949 Mm^3 and this allocation is constant throughout the years.

Industrial economic activity in the Klein and Middle Letaba is virtually non-existent hence there is no water allocation to this sector.

c) Agriculture - Irrigation

- **Groot Letaba**
  Due to the fact that various sources provide conflicting figures with regard to volumes of water requirements for Irrigation Agriculture, it is of critical importance to provide a more detailed analysis of this sector in terms of hectare and water use patterns in the Groot Letaba River Catchment.

  According to the Dam Records provided by DWAF concerning the Ebenaezer and Tzaneen Dam respectively, the amount of water allocated to the Groot Letaba Irrigation Board on an annual basis is 88 Mm^3. However data obtained from the Groot Letaba Irrigation Board gives the following breakdown in terms of climatic zones, hectares of irrigated land and water allocation

Climatic zone	Hectares	Volume(M^3/ha)	Water(Mm^3)
1	1952	6620	12.92
2	3586	8920	31.99
3	6713	10900	73.17
Total	**12251**		**118.89**

The figure in the preceding table differs as much as 30 Mm^3 from the figure provided by DWAF.

According to official records, the total number of hectares under irrigation in the Groot Letaba River Catchment is 14 420

Area	Hectares
Groot Letaba Irrigation Board	12251
Letsitele Valley	2169
Total	**14420**

According to the farmers situated in the study area, as well as other sources, water usage per hectare according to climatic zones is actually less than the official water allocation because of more sophisticated irrigation methods practised by farmers.

In Appendix 3, Annexure 2, water usage per hectare for the relevant crop patterns is shown

From this Annexure it can be deduced that a significant amount of irrigated land is in zone 3 and zone 2 respectively as they register 8 032 and 4 436 hectares respectively. In zone 1 the amount of hectares under irrigation is 1 952 hectares. The same applies with regard to water requirements, as zone 3 and zone 2's water requirements are 76.53 Mm^3 and 35.74 Mm^3 respectively. In zone 1 the water requirements amounts to 13.40 Mm^3. The total amount of water allocated for irrigation agricultural purpose is 125.67 Mm^3, which is in line with the amount published in the proposed First Edition National Water Resource Strategy of DWAF and is therefore the figure accepted .

Avocados are mainly produced in zone 1 of the Groot Letaba River area as well as the Letsitele Valley. Citrus is most prominent in zone 2 and zone 3. Bananas and Mangoes are the most prominent orchard crops produced in the areas below the Tzaneen Dam. A significant amount of tomatoes is also produced in all three zones.

Currently DWAF has finalised its water licensing process and the verification process of water resources channelled to Irrigation Agriculture is underway. The hectares under Irrigation Agriculture as supplied by farmers is also under scrutiny. To verify the figures of this two aspects will obviously be time consuming but will provide an opportunity for the availability of reliable data. For purposes of this study it was decided to consider the fact that water use for irrigation agriculture is driven by the amount of water use per hectare as well as the number of hectares under irrigation a shown in Appendix 3, Annexure 2. This calculation yielded results that are in line with those contained in DWAF's National Water Resource Strategy document.

- **Klein and Middle Letaba**
  Water use for irrigation agriculture in this sub-catchment is calculated by the amount of water use per hectare as well as the number of

hectares under irrigation. As it is shown in Table 5.9 the total number of hectares under irrigation in the Klein and Middle Letaba catchment is 4 452 and the amount of water allocated for irrigation purposes is 25 Mm³.

The amount of water required as well as the hectares and crops under consideration in the Klein and Middle Letaba are presented in Table 5-1 with the relevant quaternaries.

TABLE 5-1: KLEIN & MIDDLE LETABA CATCHMENT IRRIGATION WATER USE AREAS PLANTED (COMMERCIAL & SUBSISTENCE)

	82A	82B	82C	82D	82E	82F	82G	82H	82J	TOTAL(Ha)
Avocados	15	435	191	0	0	0	0	0	0	**641**
Bananas	0	0	0	0	0	0	350	600	0	**950**
Citrus	4	28	16	0	0	0	0	0	0	**48**
Mangoes	0	15	5	0	0	0	0	0	0	**20**
Tomatoes	442.8	1047.6	829.6	16	9	31	379	38	0	**2793**
TOTAL	**461.8**	**1525.6**	**1041.6**	**16**	**9**	**31**	**729**	**638**	**0**	**4452**

TOTAL WATER USED (M^3)

	82A	82B	82C	82D	82E	82F	82G	82H	82J	TOTAL(Mm^3)
Avocados	82500	2392500	1050500	0	0	0	0	0	0	3.53
Bananas	0	0	0	0	0	0	3185000	5460000	0	8.65
Citrus	36000	252000	144000	0	0	0	0	0	0	0.43
Mangoes	0	135000	45000	0	0	0	0	0	0	0.18
Tomatoes	1977102	4677534	3704164	71440	40185	138415	1692235	169670	0	12.47
TOTAL	2095602	7457034	4943664	71440	40185	138415	4877235	5629670	0	25.25

Data on the amount of hectares under irrigation as well as water usage per hectare for bananas, citrus, mangoes and tomatoes was obtained from a reconnaissance study to augment the water resources of the Klein and Middle Letaba River Catchment.

As can be seen from Table 5-1, tomatoes, bananas and avocados are dominant crops in the catchment . About 60-65% of total national tomato production is produced in the valley.

d) Afforestation

Afforestation is considered to be one of the activities that reduces MAR, hence it is categorised under water use activity. Data on commercial plantation water use was obtained from the current National Water Resource Strategy commissioned by DWAF (2003).

In the Groot Letaba catchment gum and pine are dominant with regard to commercial forestry. The total area of this catchment is 4 952 km^2 , gum and pine is 270 km^2 and 180 km^2 respectively.

Since 1972 it was required of timber growers to apply for permits to establish commercial plantations on new land or sections of land which, after harvest, have not been planted with trees for a period of more than 5 years. Such applications could be rejected on the assumption that afforestation would use an unacceptably high proportion of water in the catchment. In considering the permit applications, the effect of afforestation has been by means of the so-called Van der Zel curves. Although these were very useful, it was a very generalisation based on limited local data. These curves are also used in WRC report *Surface Water Resources of South Africa 1990* (WRC Report No 298/1/94).

Over period of time it has become clear that not only overall reduction in run-off is important but also reductions in low flow might be of more relevance to decision-makers. Results from earlier forest hydrology studies in South Africa indicate that the water use characteristics of eucalyptus and pine species may be quite different. There was therefore a need for an improved model that could be used for planning and decision making regarding forestations effect.

The Jonkershoek Forestry Research Centre, CSIR Division of Water, Environment and Forestry Technology from Stellenbosch was contracted by the Department of Water Affairs and Forestry to set up a number of experimental sites with the aim to develop empirical models to estimate run-off and also low flow reduction.

The results were published in Smith R.E. and Scott D.F (1992): *Simple Empirical Models to Predict Reductions in annual and Low Flows Resulting from afforestation*. A shortened version of the report was published in Water SA, Volume 23 No. 2, April 1997. Since then the formulas have become known as the CSIR models or sometimes Smith/Scott models. They have been widely applied and were also used in the National Water Resource Strategy to estimate the run-off reduction because of afforestation. For purposes of this study, it is important to know that one of the sites used for the experiments and data collection which led to the development of the empirical formulas was located on the Westfalia estate in the Groot Letaba catchment.

THE FORMULAS WERE APPLIED FOR THE PROJECT AREA AND

Table 5-2 below gives the results.

TABLE 5-2: RUN-OFF REDUCTION BY AFFORESTATION IN THE LETABA CATCHMENT

Average Plantation Age	Gum Years 6.2	Pine Years 13.2

Catchment	Total Area km²	Forest Area km²	% Forest	% Run-off Reduction	MAR 10 6m³	Run-off Reduction 10 6m³	Total Afforestation Water Use Mm³
Groot Letaba-Gum	4952	270	5.45	5.53	381	21.1	35.1
Groot Letaba-Pine	4952	180	3.63	3.69	381	14.1	
Klein Letaba-Gum	5453	24	0.43	0.44	151.9	0.7	
Klein Letaba-Pine	5453	19	0.35	0.36	151.9	0.5	1.2
TOTAL							36.4

The results of 35.1 x 10^6 m³ for the Groot Letaba and 1.2 x 10^6 m³ in the Klein/Middle Letaba correspond with the figures quoted in the National Water Resource document.

Ecology

According to the current DWAF National Water Resource Strategy, water for ecological requirements is 72 Mm³ in the Groot Letaba and 20 Mm³ in the Klein and Middle Letaba

e) Transfers-Out

Data for this entity was also obtained from the current edition of the National Water Resource Strategy commissioned by DWAF. Transfers-out of 11 Mm³ occurs in the Groot Letaba Catchment.

There are currently no transfers-out in the Klein and Middle Letaba catchment.

5.4 WATER BALANCE IN PHYSICAL UNITS

The main objective of this section is to consider the model which was constructed with regard to The Groot Letaba catchment as a computational aid to assess the balance between water supply and demand..

Normally two types of water balance are incorporated in the construction of a water balance model, which are:

- The supply / usage balance compares total supply with total use to establish whether there is a surplus or deficit and to quantify the extent or the surplus/deficit.
- The hydrological balance subtracts the consumptive use (including losses) from the catchment's water resources plus upstream flow (including

imports). The remainder, which flows to the adjacent downstream catchment, also indicates utilised water that could be harnessed for further development.

Important to note is that the successful operation of this water balance model depends to a large extent on the validity of the input parameters related to both the water resources and water use. The MAR for the Groot Letaba is available for a seventy-year period as if pristine conditions still apply.

Very few catchments are in pristine state and the volume of run-off water is affected by a number of man made activities. In the RSA two agricultural practices have been classified as run-off reduction activities, namely commercial afforestation and dry land sugar cane plantings.

Actual measurement of river flow raw data under present conditions is converted to river flow under the pristine conditions. However, since 1990, only raw data has been collected and no updated and converted data is presently available for the years since 1990.

It is convenient to classify the structure of water resource accounts into the following components, *viz*.

- Water Balance in the Groot Letaba
- Composition of water use in the Groot Letaba
- Composition of water supply in the Groot Letaba
- Over – or under utilisation of water in the Groot Letaba
- Water Balance in the Klein and Middle Letaba
- Composition of water use in the Klein and Middle Letaba
- Composition of water supply in the Klein and Middle Letaba
- Over – or under utilisation of water in the Klein and Middle Letaba

5.4.1 Groot Letaba Water Balance

Table 5-3 reflects the water balance in the Groot Letaba for 2000.

It is important to remember that much data was gathered in 2000 and the water balance situation is constantly in flux, on a seasonal as well as an annual basis. As an example, there was some confusion at the time these tables were compiled as to whether the transfers should have been set at 15 Mm3 (allocated) or 11 Mm3 (actual). Care should therefore be exercised in placing too much reliance on these data.

TABLE 5-3: WATER BALANCE IN THE GROOT LETABA SUB - CATCHMENT FOR 2000 [MILLION CUBIC METRE]

GROSS SUPPLY	[Mm³]	GROSS USE	[Mm³]	EXCESS / DEFICIT [Mm³]
- Mean annual run-off (in system)	**381.00**	**1 MUNICIPAL USE**	**15.51**	
		1.1 Households (Domestic)	**14.56**	
		1.1.1 High Income	**4.22**	
		- Outdoor	2.96	
		- Indoor	1.27	
		1.1.2 Low Income	**10.33**	
		- Outdoor	8.78	
		- Indoor	1.55	
GROSS SUPPLY	**381.0**	**1.2 INDUSTRY, MINING & OTHER**	**0.95**	
MINUS:				
- Evaporation	**17.53**			
		2 AGRICULTURAL - IRRIGATION	**125.67**	
		2.1 Avocados	5.10	
		2.2 Bananas	6.37	
NET SUPPLY	**363.47**	**2.3** Citrus	77.62	
		2.4 Mangoes	25.82	
		2.5 Others	10.76	
		3 AFFORESTATION	**35.00**	
		4 ECOLOGY	**72.00**	
PLUS: 2. RETURN FLOWS	**14**	**5 TRANSFERS - OUT**	**11.00**	
TOTAL SUPPLY	**377.47**	**TOTAL USE**	**259.17**	**118.30**

Source: Research Team calculations

From this table it can be noted that the Groot Letaba exhibits a surplus of 118.30 Mm³. This implies that in this Catchment more water was available relative to use during the year 2000 period. However this figure should be treated with caution because the so called yield, water available for use, is over extended. The yield can be increased with further infrastructure development like the construction of a new dam.

It is also important to take note of changes in water utilisation levels over time for the Groot Letaba Catchment. In Table 5-4 the utilisation level of water for this catchment is shown.

TABLE 5-4: WATER BALANCE : GROOT LETABA CATCHMENT

[PHYSICAL UNITS - Mm^3]

YEARS	TOTAL SUPPLY	AVERAGE SUPPLY	TOTAL WATER USE	SURPLUS / DEFICIT	TOTAL WATER USE / AVERAGE SUPPLY [PERCENTAGE
1991	377.47	377.47	256.47	121.00	67.9%
1992	377.47	377.47	256.74	120.73	68.0%
1993	377.47	377.47	257.02	120.45	68.1%
1994	377.47	377.47	257.31	120.16	68.2%
1995	377.47	377.47	257.60	119.87	68.2%
1996	377.47	377.47	257.90	119.57	68.3%
1997	377.47	377.47	258.21	119.26	68.4%
1998	377.47	377.47	258.52	118.95	68.5%
1999	377.47	377.47	258.84	118.63	68.6%
2000	377.47	377.47	259.17	118.30	68.7%

In order to identify the trend in the availability of water in the Groot Letaba Catchment, the following steps were followed:

Step 1: Standardise Annual run-off. Due to erratic rainfall figures it was necessary to make use of an average annual run-off. This was done by calculating an average annual run-off for the period 1991 to 2000.

Step 2: The water availability was calculated by expressing total water use as a percentage of average supply on an annual basis.

The results of these calculations are shown in the last column of Table 5.3. From this table it is apparent that the water utilisation level increased slightly from 67.9% in 1991 to 68.7% in 2000.

5.4.2 Klein and Middle Letaba Water Balance

Table 5-5 reflects the water balance in the Klein and Middle Letaba for 2000.

TABLE 5-5: WATER BALANCE IN THE KLEIN & MIDDLE LETABA CATCHMENT FOR 2000 [MILLION CUBIC METRE]

GROSS SUPPLY	[Mm^3]	GROSS USE	[Mm^3]	EXCESS / DEFICIT [Mm^3]
- Mean annual run-off (in system)	**151.90**	**1 MUNICIPAL USE**	**11.06**	
		1.1 Households (Domestic)	**11.06**	
		1.1.1 High Income	**2.99**	
		- Outdoor	2.09	
		- Indoor	0.90	
		1.1.2 Low Income	**8.07**	
		- Outdoor	6.86	
		- Indoor	1.21	
GROSS SUPPLY	**151.9**	**1.2 INDUSTRY, MINING & OTHER**	**0.00**	
MINUS:				
- Evaporation	**31.21**			
		2. AGRICULTURAL - IRRIGATION	**25.25**	
		2.1 Avocados	3.53	
		2.2 Bananas	8.65	
NET SUPPLY	**120.69**	**2.3** Citrus	0.43	
		2.4 Mangoes	0.18	
		2.5 Tomatoes	12.47	
		3 AFFORESTATION	**1.00**	
			0.00	
		4 ECOLOGY	**20.00**	
			0.00	
PLUS: 2. RETURN FLOWS	**2**	**5 TRANSFERS - OUT**	**0.00**	
TOTAL SUPPLY	**122.69**	**TOTAL USE**	**57.31**	**65.38**

Source: Research team calculations

From this table it can be noted that the Klein and Middle Letaba exhibits a surplus of 68.38 Mm³ if water use is compared with MAR. It is, however, well known that if use is compared with yield, periods of shortage occurs regularly.

It is also important to take note of changes in water utilisation levels over time for the Klein and Middle Letaba Catchment. In Table 5-6 the utilisation level of water for this catchment is shown.

TABLE 5-6: WATER BALANCE : KLEIN & MIDDLE LETABA CATCHMENT [PHYSICAL UNITS – MM^3]

YEARS	TOTAL SUPPLY	AVERAGE SUPPLY	TOTAL WATER USE	SURPLUS / DEFICIT	TOTAL WATER USE / AVERAGE SUPPLY [PERCENTAGE
1991	122.69	122.69	55.26	67.43	45.0%
1992	122.69	122.69	55.47	67.22	45.2%
1993	122.69	122.69	55.68	67.01	45.4%
1994	122.69	122.69	55.90	66.79	45.6%
1995	122.69	122.69	56.12	66.57	45.7%
1996	122.69	122.69	56.35	66.34	45.9%
1997	122.69	122.69	56.58	66.11	46.1%
1998	122.69	122.69	56.82	65.87	46.3%
1999	122.69	122.69	57.06	65.63	46.5%
2000	122.69	122.69	57.31	65.38	46.7%

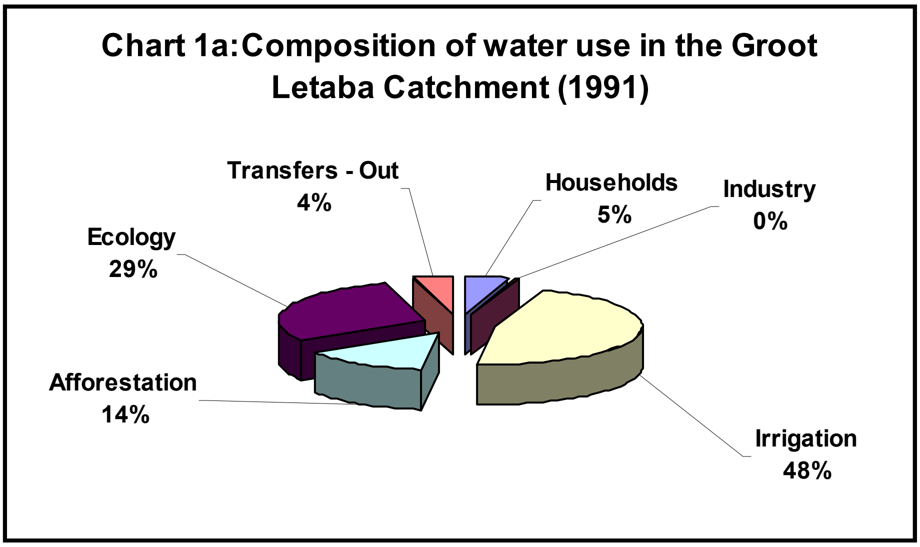
It is important to note the fact that it is very difficult to arrive at conclusions regarding the utilisation of water over time if the real annual supply and use figures are compared separately. This is due to the fact that the supply of water (i.e. rainfall) is very erratic on a year to year basis. In order to identify the trend in the availability of water in the Klein and Middle Letaba Catchment, the same steps were followed as in the case of the Groot Letaba.

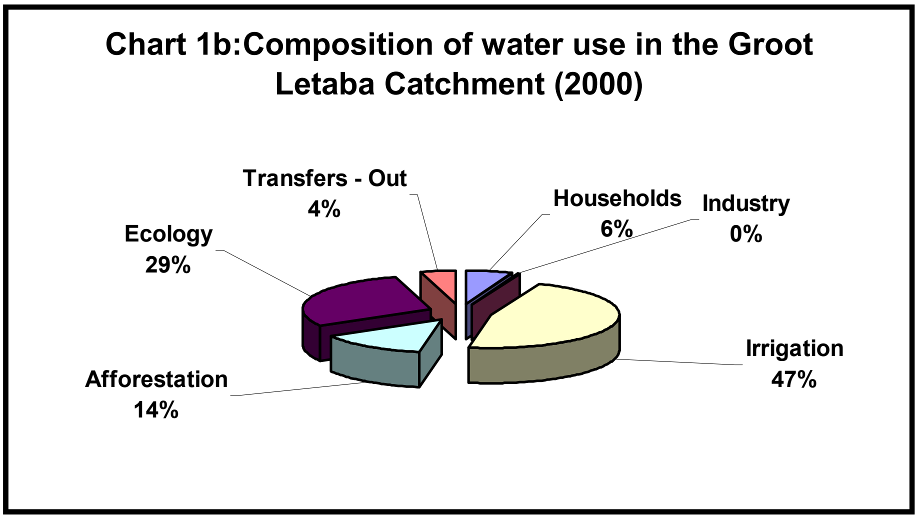
The results of these calculations are shown in the last column of Table 5-6. From these tables it is apparent that the water utilisation level increased slightly from 45.0% in 1991 to 46.7% in 2000.

Composition of Water Use

Appendix 3, Annexure 3, shows the percentage composition of sectoral water use for the Groot Letaba catchment for the period 1991 to 2000. From this table it is evident that water requirements for both Irrigation Agriculture and Ecology respectively are a paramount feature. The other main users of water are forestation and household. Transfers-out and households represent a relatively small portion of total water use.

Charts 1a and 1b also represent the breakdown of the composition of sectoral water use for the Groot Letaba catchment for 1991 and 2000 respectively.





From the charts it can be observed that Irrigation Agriculture, as well as Ecology, are still the main users of water as their water utilisation level stood at 48% and 29% respectively relative to total water use in the year 1991. In 2000 the utilisation level stood at 47% and 29% for Irrigation Agriculture and Ecology respectively, which indicates a slight decrease over the period with regard to Ecology. Important to note is that water allocated to irrigation Agriculture remains constant over the period. The other important users are afforestation, households as well as transfers-out. Afforestation as well as transfers-out exhibits a slight decline as a percentage of total water use on the period. Households, on the other hand, show a slight increase over the period from 5% in 1991 to 6% in 2000 relative to total water.

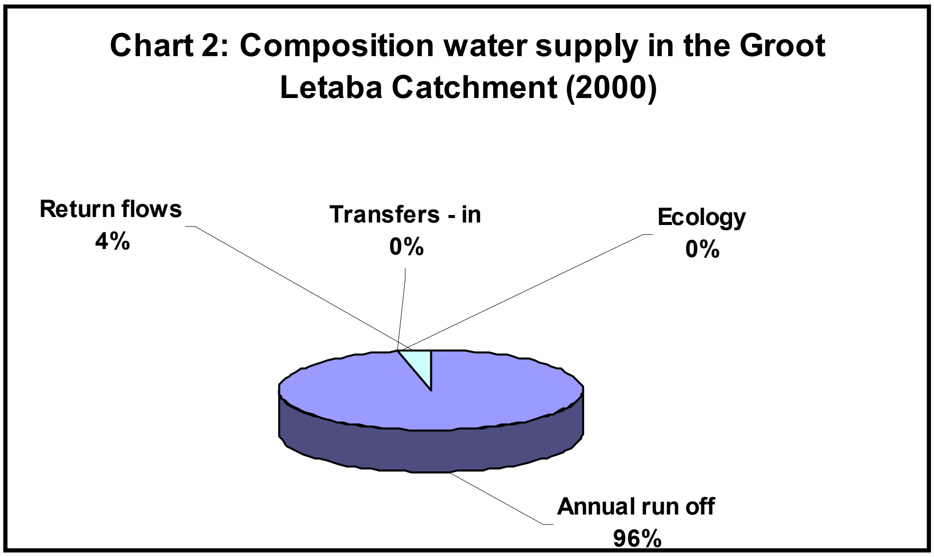
Appendix 3, Annexure 6, shows the percentage composition of sectoral water use for the Klein and Middle Letaba catchment for the period 1991 to 2000. From this table it is evident that water requirements for both Ecology and Irrigation Agriculture respectively, are a paramount feature. The other main user of water is households. Forestation represents a relatively small portion of total water use.

Important to note is that, while household water use increases relative to total water use over the period, irrigation agriculture as well as ecology exhibits a slight decline relative to total water use.

Chart 3a and 3b also represents the breakdown of the composition of sectoral water use for the Klein and Middle Letaba catchment for 1991 and 2000 respectively.

In this section the focus is on the components of water supply in the Groot Letaba Catchment. Appendix 3, Annexure 4, shows the composition of water supply in this catchment.

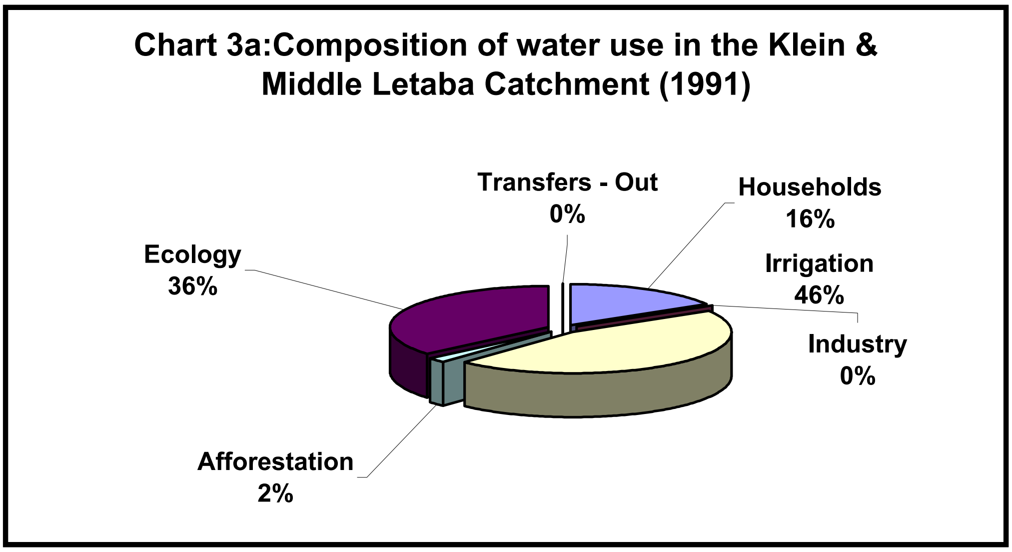
Chart 2 gives a breakdown of components of water supply in the Groot Letaba for the year 2000. Important to note is that annual run-off and return flows happen to be the main components of supply. Transfers-in are not occurrences with regard to this particular catchment. The reason why only the 2000 scenario is shown, is due to the fact that no reliable data was forthcoming with regard to other supply components for other years, hence a decision was made to leave them constant. Only data pertaining to Annual run-off and return flows was obtained.

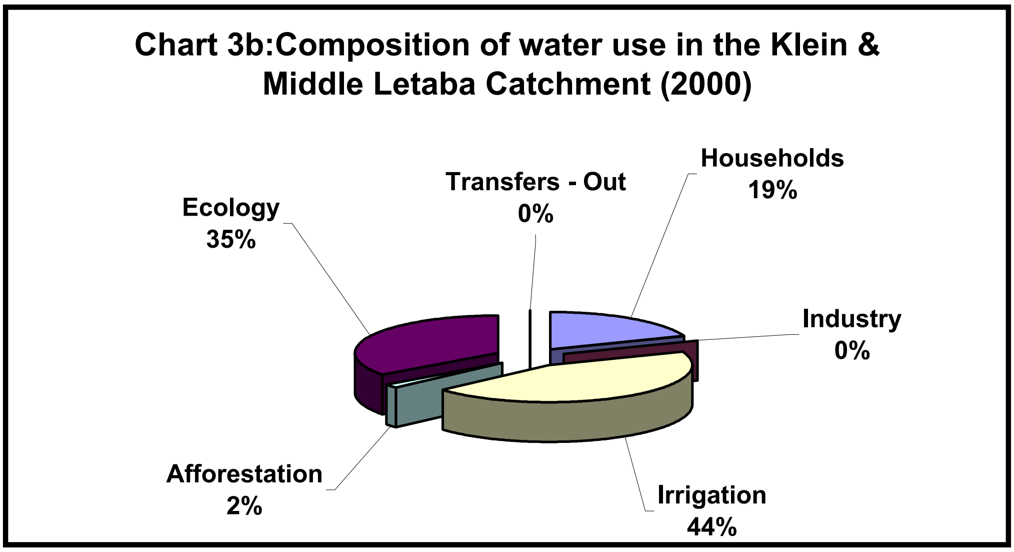


As seen from Chart 2, annual run-off makes a significant contribution with regard to total water supply. It contributes 96% compared to 4% of return flows.

In this section the focus is on the components of water supply in the Klein and Middle Letaba Catchment.

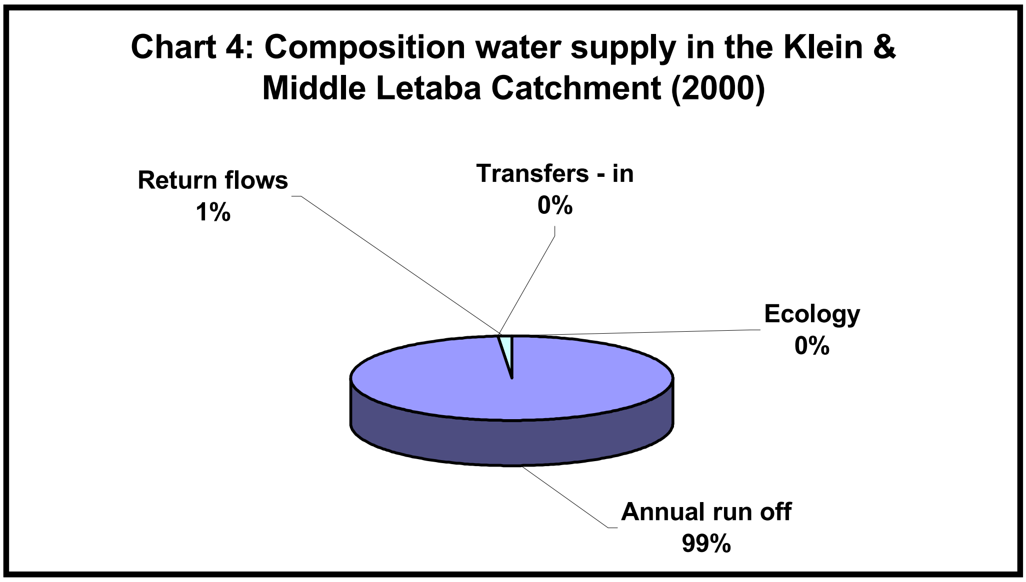
Chart 4 gives a breakdown of components of water supply in the Klein and Middle Letaba for the period 2000. Important to note is that annual run-off and return flows happen to be the main components of supply. Transfers-in is not an occurrence with regard to this particular catchment. The reason only the 2000 scenario is shown, is due to the fact that no reliable data was forthcoming with regard to other supply components for other years, hence a decision was made to leave them constant. Only data pertaining to Annual run-off and return flows was obtained.





From the charts 3a and 3b, it can be observed that Ecology as well as Irrigation Agriculture is still the main users of water as their water utilisation level stood at 36% and 46% respectively relative to total water use in the year 1991. In 2000 the utilisation level stood at 35% and 44%, for Ecology and Irrigation Agriculture respectively, which indicates a slight decrease over the period with regard to both Ecology and irrigation agriculture. Forestation exhibits a constant pattern. Households, on the other hand, show a slight increase over the period from 16% in 1991 to 19% in 2000 relative to total water.

Composition of Water Supply



As seen from chart 4, annual run-off makes a significant contribution with regard to total water supply. It contributes 99% compared to 1% of return flows.

5.4.3 Letaba Catchment Water Balance

Table 5-7 reflects the water balance in the Letaba basin for 2000.

TABLE 5-7: WATER BALANCE IN THE LETABA BASIN FOR 2000

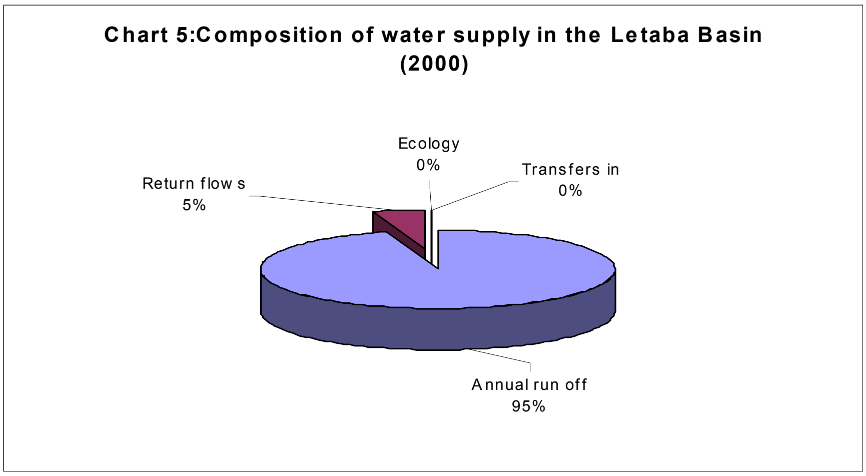
GROSS SUPPLY	[Mm^3]	GROSS USE	[Mm^3]	EXCESS / DEFICIT [Mm^3]
- Mean annual run-off (in system)	**532.90**	**1 MUNICIPAL USE**	**26.57**	
		1.1 Households (Domestic)	**25.62**	
		1.1.1 High Income	**7.22**	
		- Outdoor	5.05	
		- Indoor	2.17	
		1.1.2 Low Income	**18.40**	
		- Outdoor	15.64	
		- Indoor	2.76	
GROSS SUPPLY	**532.90**	**1.2 INDUSTRY, MINING & OTHER**	**0.95**	
MINUS:				
- Evaporation	**48.74**			
		2 AGRICULTURAL - IRRIGATION	**150.93**	
		2.1 Avocados	8.63	
		2.2 Bananas	15.02	
NET SUPPLY	**181.16**	**2.3** Citrus	78.05	
		2.4 Mangoes	26.00	
		2.5 Tomatoes	23.23	
		3 AFFORESTATION	**36**	
		4 ECOLOGY	**92**	
PLUS: 2. RETURN FLOWS	**16**	**5 TRANSFERS - OUT**	**11.00**	
TOTAL SUPPLY	**500.16**	**TOTAL USE**	**316.50**	**183.66**

Source: Research team Calculation

From table 5.8 it can be noted that in the total Letaba basin there is still 183.66 Mm³ of uncommitted water. It must however be remembered that this water is unexploitable with present infrastructure development.

Composition of Water Supply

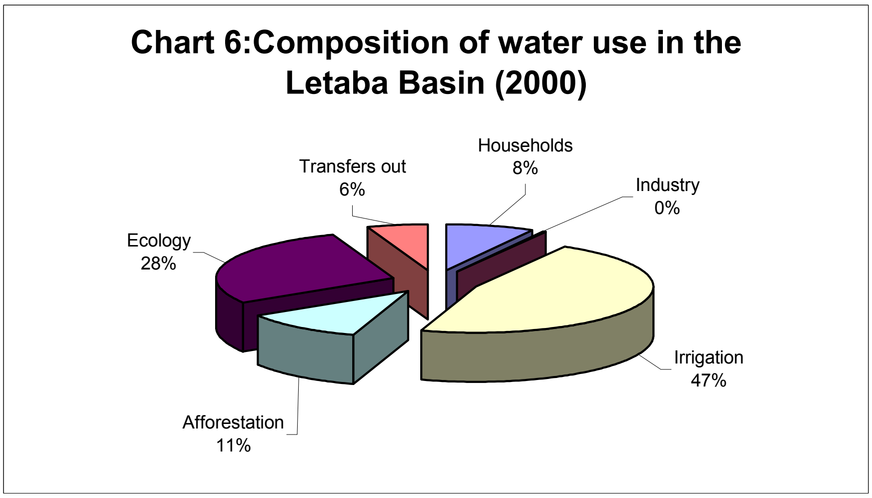
In Chart 5 the composition of the water supply sectors in the Letaba is presented.



It is obvious from chart 5 that the only sources of water supply at present is annual run-off and return flows.

Composition of Water Use

In Chart 6 the composition of water use in the year 2000 is presented.



From chart 6 it is obvious that nearly 50% of water used is by irrigation with the inflow requirements for ecology at 28% the second highest.

5.5 Future Water Use Trends

5.5.1 Water Use Projections

The essential task of the Water Balance Model in this study was to provide a computational framework for establishing the current pattern of water availability and use in the catchment. It can, however, also be used as a framework for future water usage/availability forecasting.

These water use forecasts should also incorporate intervention measures, usually referred to as water use(demand) management. Typical forms of water use management include the adjustment of the price of water and more frequent restrictions on the use of water for non-essential purposes to encourage reduced water usage.

Water demand management is aimed at reducing water use, but there are factors that will result in an increase in use on a per capita basis. For example, the current RDP program is focused on ensuring the supply of a minimum per capita volume, particularly to those people in the rural areas. Urban per capita use is expected to increase as standpipes are replaced with reticulated water to individual dwellings. Installation of water-borne sewage will increase demand but will also enhance return flows.

As mentioned earlier, any changes in water demand in the Letaba River areas could result ultimately in the reallocation of water supplies between the various users groups. Within the present water policy, specific water volumes must be supplied for primary users as well as additional instream flow releases to secure a given level of ecological status. These two sectors form the primary reserve and their demands will influence the water available for agriculture. The possible supplementation of water supplies for current as well as future requirements must be looked into.

According to the DWAF Strategic Resource Plan, the secure available annual yield in the project area is 192 Mm^3 while the estimated annual use in 2000 is already 223 Mm^3, if the ecological reserve of 92 Mm^3 is excluded but run-off reduction by afforestation is included. This is an indication that the ecological reserve, and therefore the natural health, of the Letaba is suffering acute shortages at certain times of the year and is occurring despite the fact that in terms of Annual Run-off there is still an annual surplus of 183 Mm^3.

According to the National Water Resource Strategy, the base scenario for the project area in terms of use would be 226 Mm^3 in 2023 and the high scenario 228 Mm^3. It is therefore evident that there is no surplus yield available presently and that the position can only deteriorate in future if no extra provision is made to increase the yield.

Furthermore, the scenarios are based on existing infrastructure, the construction of the Nandoni Dam as well as return flows resulting from growth in requirements. They are also incorporating growth in water requirements as a result of population growth as well as general economic development.

Estimates of future primary water requirements are fraught with uncertainties because of the diverse settlement patterns. This range from long established, well-developed urban areas like Tzaneen, to less developed urban areas like Nkowankowa, semi-urbanised communities and rural villages. Social forces influencing settlement patterns and urbanisation are not well understood and the influence of aspects such as migration (both within South Africa and from

Mozambique and elsewhere) and infectious diseases further complicates the projections. Of considerable importance is the uncertainty associated with official population statistics and their interpretation in various previous studies.

Although the water balance constructed for both the Groot Letaba and the Middle and Klein Letaba shows a surplus over the time series considered (1991-2000), it must be emphasised that periods of water shortage for irrigation have placed this sector under severe stress. This is attributed to the fact that within the present water policy, specific water volumes must be supplied for primary users and as well as additional instream flow releases to secure a given level of ecological status.

The reaction of irrigators has been to invest in technology and management skills, concentrate on high value crops (mainly fruit) and exploit other water sources such as groundwater in order to maximise the use of their restricted quotas.

These developments inevitably led to improved irrigation management practises including scientific observations of field conditions and the use of modern irrigation equipment, mainly highly efficient micro jet and drip irrigation systems. Flood irrigation is virtually non-existent. Although irrigated agriculture is highly developed in the catchment, black farmers have only recently gained access to viable commercial units. There is an urgent need to develop individual as well as small emerging farmers from the rural communities in order to improve and sustain the socio-economy of the region and significantly increase household incomes among the impoverished communities.

5.6 CONCLUSIONS

The most important conclusion to be drawn from this study is that it was possible to compile acceptable water resource accounts for the Letaba River Catchment. However, much emphasis was placed on the construction of the water balance model and not other aspects of water resource accounting such as asset accounts.

The Letaba River Catchment has been the subject of many studies; as a result some detailed data with regard to water use as well as water supply was obtained. However, it is important to note that some of the official documents give contrasting data on issues such as the number of hectares of irrigated land, water use requirements, water quotas as well as other pertinent issues which form an important part of this study. To obtain reliable data, it was necessary to grasp the situation on the ground and this was done by contacting role players such as growers associations, farmers as well as the irrigation board. The National Water Resource Strategy, which is updated on a regular basis, formed an important source of information with regard to water use and supply information used in this study.

The next four Chapters deal with the water usage in each of the four main sectors being investigated, and with the construction and exercising of the models to synthesise the water demand schedules.

6 AGRICULTURAL WATER

6.1 OVERVIEW OF PHYSICAL RESOURCES

The range of agricultural products produced in the Groot, Klein and Middle Letaba Catchment varies considerably due to different climatic conditions prevailing in these regions. In the Groot Letaba three different climatic zones occur which influence the crops cultivated. A very diverse crop pattern exists in the Groot Letaba, with avocados, bananas, mangoes, litchis, macadamias and vegetables being the main crops. Avocados and bananas are the most predominant crops in the wet and more humid climatic zone 1 whilst the others are grown in the more arid zone 2 and zone 3 respectively. In the Klein and Middle Letaba tomatoes (and other vegetables) are the dominant crop with a range of other crops produced in small quantities. The crop pattern selected as being representative for purposes of this study was motivated by these considerations.

Groot Letaba

Along the Groot Letaba the main irrigation board controls most of the activities related to Irrigation Agriculture. The total proclaimed irrigation quota area of the Groot Letaba Main Irrigation Board is 14 420 ha and this is subdivided in three zones. The irrigation entitlement area in Zone 1 is 1 952 ha, with 4 436 ha in Zone 2 and 5 863 ha in Zone 3 respectively.

As stated in the previous chapter, DWAF has finalised the water licensing process and will, over a period of time, conduct a verification process which will then make more reliable data available.

Another 2 169 ha are irrigated along the Letsitele River and Lower Letaba by pumping water straight from the river, and this has been included in Zone 3 total for calculation purposes. This gives a total of 14 420 hectares irrigated, which figure is used for purposes of this study as discussed in the chapter on water balance. There is some conflict between sources relating to the number of hectares under irrigated land. One of the reasons for this is that, by using modern irrigation techniques, farmers can actually irrigate bigger areas than the original hectares listed in some official documents. In some cases it is due to the fact that land is available but because of periodic shortages of water experienced, it is not cultivated.

The amount of irrigation water allocated per hectare for climatic Zone 1, 2 and 3 is 6 620 m^3, 8 920 m^3 and 10 900 m^3 respectively. These quotas are applicable for irrigation districts situated along both the Ebenaezer and the Tzaneen Dam. Although during rainy periods farmers use less water, the quantity of irrigation water utilised in calculations in this study were determined by consideration of the physiological needs of the crops under consideration multiplied by the number of hectares cultivated.

Tomatoes constitute a mere 10% of total land under irrigation water (in strong contrast to the Klein and Middle Letaba where tomatoes are dominant, and avocados and bananas are less significant).

As mentioned earlier in this chapter, various types of crops identified for purposes of this study are grown in different climatic zones. Climatic zone 1 is more humid than climatic zone 2 and 3, which are more arid. The implication is that crops, which are grown in climatic zone 2 and 3, might require more irrigation water.

In Table 6-1 below the make-up of irrigation agriculture in terms of hectares and irrigation water use is given per climatic zone with regard to the Groot Letaba. Again note that for the purposes of this study the 2169 hectares irrigated along the Letsitele River is added to zone 3 of the Groot Letaba.

TABLE 6-1: MAKE-UP OF IRRIGATION AGRICULTURE PER ZONE IN 2002

Crop	GROOT LETABA CATCHMENT			
	Hectares		Irrigation Water use	
	Number	Percentage	m^3	Percentage
ZONE 1	1 952	13%	13 402 250	11%
ZONE 2	4 436	31%	35 771 000	28%
ZONE 3	8 032	56%	76 529 622	61%
TOTAL	14 420	100%	125 702 872	100%

From Table 6-1 it is evident that a significant amount of irrigated land is in climatic zone 3 as it constitutes 56% relative to the total irrigated land. On the other hand, 61% of irrigation water is applied in zone 3. Climatic zone 2's share of irrigated land is 31% and its water use is 28%. From this table it is also evident that only a small portion of land as well as irrigation water is applied in zone 1, which is more humid. However, given the fact that 89% of irrigated land relative to total land when both zone 2 and 3 are combined, it implies that most of irrigated agriculture in the Groot Letaba occurs in the more arid areas which would require more irrigation water.

Data with regard to irrigation requirements as well as number of hectares was obtained from important role players in the Groot Letaba with regard to individual crops. (For purposes of this study is was assumed that water requirement in terms of cubic meters per hectare for different crops is the same for Klein , Middle Letaba and The Groot Letaba.)

In Table 6.2 the make-up of individual crops for the Groot Letaba according to each climatic zone is given.

TABLE 6-2 MAKE-UP OF INDIVIDUAL CROPS IN THE GROOT LETABA AND LETSITELE IRRIGATION AREA IN 2002

	ZONE 1				ZONE 2				ZONE 3				TOTAL GROOT LETABA			
Crop	Hectares		Irrigation Water use		Hectares		Irrigation Water use		Hectares		Total Water use		Hectares		Total Water use	
	Number	%	m^3	%	Number	%	m^3	%	Number	%	m^3	%	Number	%	m^3	%
AVOCADOS	1252	64	6 886 000	51	0	0	0	0	0	0	0	0	1252	9	6 886 000	6
BANANAS	700	36	6 516 250	49	0	0	0	0	0	0	0	0	700	5	6 516 250	5
CITRUS	0	0	0	0	3 186	72	27 081 000	76	5 377	67	53 264 562	70	8 563	59	80 345 562	64
MANGOES	0	0	0	0	800	18	6 800 000	19	2 010	25	19 911 060	26	2 810	20	26 711 060	21
TOMATOES	0	0	0	0	450	10	1 890 000	5	645	8	3 354 000	4	1095	7	5 244 000	4
TOTAL	1 952	100	13 402 250	100	4 436	100	35 771 000	100	8 032	100	76 529 622	100	14 420	100	125 702 872	100

NB:- In the case of mangoes other important tree crops like macadamias and litchis are included. All vegetables are grouped with tomatoes.

As can be seen in Table 6.2, citrus constitutes a significant share of 59% relative to a total of 14420 hectares of irrigated land. On the other hand it consumes 64% of irrigation water relative to the total irrigation water in the Groot Letaba. Mangoes, which for the purposes of this study, was classified with other fruit crops constitute 20% of the total irrigated land and 21% of total irrigation water. Effectively these two crops use 85% of the available irrigation water in the Groot Letaba and Letsitele rivers.

Klein and Middle Letaba

The crops used for calculations in the Klein and Middle Letaba are the same as those chosen for the Groot Letaba, although the mix differs considerably.

In general, more reliable data is available for these areas and the data used in this study was obtained from research projects previously conducted by Water Systems Management (WSM).

In Table 6-2 below the make-up of individual crops is shown for the Klein and Middle Letaba.

In the case of tomatoes, it should be noted that the actual number of hectares cultivated annually differs considerably from the number of hectares under production. This can be attributed to the practice followed in the production of tomatoes which involves a situation whereby after a tomato crop has been harvested, its area is allowed to rest for at least 4 cycles before planting can resume again.

TABLE 6-3 MAKE-UP OF INDIVIDUAL CROPS IN KLEIN/MIDDLE LETABA IN 2002

Crop	Hectares		Irrigation Water Use		
	Number	Percentage	m^3/ha	Total (m^3)	Percentage
Avocados	1 229	28%	5500	6 759 500	27%
Bananas	370	8%	9100	3 367 000	13%
Citrus	40	1%	9063	362 520	1%
Mangoes	20	0%	9191	183 820	1%
Tomatoes	2 793	63%	5220	14 580 410	58%
Total	4 452	100%		25 253 250	100%

Source: Water Systems Management (WSM)

As shown in Table 6-3, irrigated land under tomato production in the Klein and Middle Letaba constitutes 63% relative to the total number of 4 452 hectares under irrigated agriculture. On the other hand, 58% of the total irrigation water use in the Klein and Middle Letaba is consumed by tomatoes. Bananas as well as avocados also constitute a significant portion of irrigated land with a share of 8% and 28% respectively relative to the total number of hectares. With regard to irrigation water use they consume 13% and 27% of irrigation water respectively relative to total irrigation water. Citrus and mangoes' share of irrigated land as well as irrigation water use is less significant.

The most recent data gives the total area cultivated on an annual basis as 4 452 hectares and irrigation water use as 25.3 Mm^3 in the Klein and Middle Letaba. However, the total hectares available for irrigation agriculture is $\pm$13 400 hectares. It must be kept in mind that tomatoes make up the bulk of the irrigation production in the Klein and Middle Letaba and that the cultivation process followed allows for one production cycle and four cycles where the soil is allowed to recover. The reason for this is that tomatoes often introduce certain diseases to the soil and producers can either treat the soil with chemicals or let it lie fallow.

Groot, Klein and Middle Letaba Consolidated

In Table 6-4 the crop and water data is consolidated into one representative table for the whole for the study region.

TABLE 6-4: IRRIGATED AREA AND WATER USE FOR THE TOTAL CATCHMENT

Crop	Catchment Irrigated Area			Water Use		
	Groot Letaba Hectares	Klein & Middle Letaba Hectares	Total Area Hectares	Groot Letaba Mm^3	Klein & Middle Letaba Mm^3	Total Mm^3
Avocados	1 252	1 229	2 481	6.9	6.7	13.6
Bananas	700	370	1 070	6.5	3.4	9.9
Citrus	8 563	40	8 603	80.3	0.4	80.7
Mangoes	2 810	20	2 830	26.7	0.2	26.9
Tomatoes	1 095	2 793	3 888	5.3	14.6	19.9
Total	14 420	4 452	18 872	125.7	25.3	151.0

Source: Water Systems Management (WSM)

From this table it is clear that citrus , tomatoes and avocados are the dominant crops in the project area.

6.2 METHODOLOGY FOR COMPILING THE WHOLE FARM BUDGET

The approach chosen for determining the economic demand schedules for water in the agricultural sector was to use farm budgets to establish a residual representing the value of water. These budgets were then incorporated in a linear programme objective function in order to determine the shadow price of water as various operating constraints changed. To achieve this, farm budgets were constructed for selected crops, and these were then consolidated into a regional budget representing the whole of the study area, regarded as a single, regional farm. This Regional Farm Budget then provided the basis for the LP objective function. The crop budgets were prepared on a per-hectare basis, and then scaled up to cover the appropriate number of hectares.

Difficulty was experienced with the alternative approach of constructing representative farms of various sizes because the complications of differing climatic zones and different crops in the different areas skewed the picture.

Five crops were identified as a representative sample of the products produced namely bananas, avocados, citrus, mangoes and tomatoes. Crop budgets for each of these crops were drawn up and a gross margin for each was calculated and then weighed in by using the number of hectares per crop to form a regional farm and determine the gross farm income per hectare

In each budget only direct costs associated with the production of the crop was used, namely items like seed, trees, fertiliser, pesticides, irrigation costs, harvesting costs and labour directly associated with the product.

From the Gross Farm Income (GFI), general farm costs like depreciation, insurance, repairs and maintenance, administration costs, fuel and electricity, etc. were deducted to determine Net Farm Income (NFI) per hectare.

From the NFI interest on land and capital investment and a management fee were deducted to determine Net Income (NI) per hectare.

The value of land can be calculated empirically but in this case it was considered to be more suitable to use the market value of land. After consultation with role players in the area, it was decided to use R3 500 per hectare as the price for undeveloped land with the potential to be irrigated. This is then also the value of present irrigated land excluding any development on the land like orchards, drip irrigation systems, bulk water systems or buildings.

6.2.1 Data Sources

The Combud Enterprise Budgets for the Limpopo Province by the Department of Agriculture were used as pro-forma for compiling crop budgets for the five crops identified for purposes of this study.

To ensure that these budgets are representative of the Letaba study area, technical experts based in that region with regard to each individual crop were consulted. The purpose was to update data used in these budgets and to gather recent control figures.

This involved a wide spectrum of important players in distinct industries associated with each crop, such as farmers in the Letaba area as well as various associations, for instance, the South African Banana Growers Association (SABGA), the South African Avocado Growers Association (SAAGA), Citrus Growers Association, the Fresh Producers Association as well as some individual growers. From interaction with these various bodies, recent data on issues surrounding yields, inputs as well as farming practices in general was obtained.

It should be noted that there have been substantial increases in some inputs to the enterprise budgets between 2002, which is the base date of this report, and 2004. More specifically, these refer to increases in electricity and the effects of the introduction of basic minimum wages for farm workers. Whilst such changes cannot be incorporated into this study as they lie beyond our base date, it is important that readers be aware of this situation lest they be tempted to impute results and conclusions reached here to the present without due care and consideration.

6.2.2 Crop Budgets

The main objective of compiling crop budgets for the crops mentioned in this section is to use them as the basis of determining Net Income for a representative farm. This variable is an important parameter in determining the value of irrigated land as well as the economic value of irrigation water, which is the core of the study.

Furthermore, information from the crop budget pertaining to aspects such as water requirements, Gross Income, Variable Costs, etc. forms important parameters that form exogenous data supplied to the linear programming model that forms an important step in determining the value of water.

Increased water use efficiency is of critical importance. Water use efficiency in terms of gross margin per volume of irrigation water should be carefully looked into, more so that increasing irrigation efficiency may enable more land to be irrigated.

Structure of a crop budget

GROSS REVENUE	
Less:	• **Variable costs** • **Marketing costs** • **Fertiliser** • **Microelements** • **Pesticides & Herbicides** • **Irrigation equipment** • **Land preparations** • **Plant Material** • **Interest on working capital**
Equals: GROSS MARGIN	

<u>Gross Revenue</u>

Gross Revenue is arrived at by multiplying a quantity of a specific crop by the price per unit of that crop. The latter might entail Rand per carton, Rand per pallet or Rand per ton depending on a unit of measurement for individual crops. On the other hand quantity might assume any unit such as a ton or a kilogram

<u>Variable Costs</u>

Variable costs vary depending on the type of crop under scrutiny; variable costs can be directly or indirectly allocable. The latter are costs that cannot normally be allocated to a specific enterprise without detailed record keeping, e.g. fuel, repair costs, lubrication costs, etc. Directly allocable costs are those that can easily be determined by means of simple record keeping, e.g. fertiliser and chemicals.

Gross Margins

It is normally the difference between Gross Income and Variable Costs and it is also determined per hectare.

Fixed costs items such as labour were not taken into account in determining Gross Margins but were included in conjunction with other relevant costs in calculating Net Income for a representative farm

In compiling the crop budgets 2003 market prices were used. Furthermore the issue of farm gate income was also carefully looked into, to avoid double counting. Crop budgets for various crops are contained in Appendix 3, Annexure 8 to 13.

6.2.3 Avocados

Avocados comprise two types of cultivars namely Hass and Fuerte in the study area.

Avocados: Fuerte

In Annexure 8 the most important budget information for Avocados – Fuerte with regard to establishment, young, medium aged and mature trees is shown. With regard to Fuerte establishment was considered as from year 0 to year 1 as no fruit is produced in this period, medium aged as from year 2 to year 4 and mature from year 5-11. The average number of avocado trees planted per hectare is 204.

Avocados: Hass

In Annexure 9 the budget information for avos – Hass cultivar is depicted. As is the case with Avos – Fuerte cultivar the budget information was compiled for establishment, young, medium aged as well as mature trees. In this case establishment was also considered to be from year 0 to year 1 as no fruit is produced, medium aged as from year 2 to 4 and mature from years 5-11. The average number of trees planted per hectare is also 204.

Irrigation Water Use

Both cultivars have the same water requirements as they use 5 500 m^3 of water per hectare. The total number of hectares under irrigated land for avocados in the project region is 2 481. This translates to 13.6 million cubic meters of irrigation water use. It must be taken into account that this study only concentrated on avocados under irrigation. The latest survey indicates a figure of 4 524 ha in production, including the non-irrigated areas.

6.2.4 Bananas

Combud Enterprise Budgets were used as a basis to compile pro-forma budget for bananas. To update and establish the reliability of these data, important role players in this industry such as the South African Banana Growers

Association, Farmer associations as well as individual farmers in the Letaba were consulted.

Crop Budget

In Annexure 10, crop budget information for bananas is shown. Banana trees reach a stage of maturity very quickly. If the establishment period is year 0, then in year 1 yield is already realised. The average number of trees planted per hectare is 2 000. The entire yield is destined for the local market

Average municipal market price	R39.00/carton
Less Marketing Costs *	R21.15/carton
(*Carton price, transport, ripening and agents fees, etc.)	R17.85/carton

Irrigation Water Use

Water requirements for bananas are 9 237m^3 per hectare.

For this study the figure of 1 070 hectares were used. This translates to 9.9 million cubic meters of irrigation water utilised in this region.

In Annexure 10 it can also be seen that bananas exhibits a positive Gross Margin per cubic meter.

6.2.5 Citrus

The Combud Enterprise Budget was used as a basis for information on Citrus budget information. To update and improve this data the Citrus Growers Association as well as individual growers were consulted.

There exist various cultivars of citrus fruit. With regard to this study Valencias are the focus of attention, as they appear to be the most dominant cultivar in the Letaba.

Crop Budget

In Annexure 11 the citrus crop budget information is shown. The average number of trees planted per hectare with regard to citrus is 475. For young and medium aged trees the total yield is less than 40 tons. For mature trees the yield is 44.3 tons. With regard to these crops young trees are about 2-3 years old, medium aged trees about 4-10 years old. Mature trees are from 11 years up.

The average gross farm income is R82 031 per hectare.

In order to arrive at Gross Income, farm gate income was used .

Irrigation Water Use

Water requirements for Citrus is 9 381 m^3 /ha, taken as weighted average of water usage in all three climatic zones. The number of hectares with regard to citrus under irrigation in total is 8 603. This translates to 80.7 million cubic metres of irrigation water. When the total amount of irrigation water use of 80.7 Mm^3 for citrus is considered relative to the total amount of 151 Mm3 for irrigation water in the Letaba, it implies that 53.4% of irrigation water in the Letaba is utilised by citrus.

6.2.6 Mangoes

In compiling costs for the crop budgets for mangoes, citrus information was used as a proxy for mangoes given similarities between the two types of trees. However expert advice from important role players in this industry was also sought.

Crop Budget

In Annexure 12 the budget information for mangoes is shown. Given year 0 to be the establishment stage, young trees begin producing yield in year 4, which is normally 4 tons per hectare. Mature trees are from year 5 to year 11 and their yield ranges from 15 tons to 18 tons per hectare. The average number of trees per hectare is also considered to be 475. With regard to mangoes, a greater percentage of total yield is earmarked for the fresh market, in this case 35%. The export as well as the processing sector only constitutes 25% each relative to the total yield. The local market receives only 15% of the total yield. The prices per ton for export, fresh produce, local market as well as processing are R4 500, R3 000, R1 500 and R1 200 respectively.

Irrigation Water Use

As is the with regard to citrus, mangoes consume 9 191m^3 of water per hectare. With regard to the Letaba, 2 830 hectares of irrigated land are for the production of mangoes in the total region and the total water use is 26.9 Mm^3.

6.2.7 Tomatoes

Data with regard to tomatoes was obtained from the Fresh Producers Association and prominent farmers in the area.

Crop Budget

As can be seen from Annexure 13, nearly the entire tomato production ends up in the National Fresh Produce markets. Tomatoes exhibit very high gross margins. The gross margin per hectare as shown in Annexure 12 is R31 192.00 per hectare. In essence, tomatoes, when compared to all the crops discussed, have the highest water use efficiency if measured in terms of the gross margin per volume of irrigation water. Tomatoes are also considered as a high-value crop characterised by inherent high risks.

Irrigation Water Use

In the Groot Letaba tomatoes (or other vegetables) are grown on 1 095 hectares of irrigated land.

In the Klein and Middle Letaba tomatoes are the dominant crops. This is due to the fact that 2 793 hectares out of total 4 452 hectares of irrigated land are under tomato production. In terms of the whole Letaba catchment this translates to 20.6% of total irrigated land and 53.4% of irrigation water used.

This crop has also a very low water requirement compared to all the crops discussed in this section and it exhibits a very high gross margin per cubic meter. Water requirement per hectare for tomatoes stands at 5 099m^3 and the gross margin per m^3 is R6.68.

6.3 A CONSOLIDATED FARM BUDGET

After compiling crop budgets for individual crops the next step involved aggregating these into a regional farm.

The table below gives a break down of the crops, hectares and total water use. All other tree crops are included with mangoes and other vegetables with tomatoes.

Crop	Area Hectares	Water Use Mm^3
Avocados	2481	13.6
Bananas	1070	9.9
Citrus	8603	80.7
Mangoes	2830	26.9
Tomatoes	3888	19.9
	18872	151.0

Important to note is the fact that in determining the Gross Product Margin, only variable costs were subtracted from the Gross Revenue with regard to each crop. To arrive at a single figure for Gross Margin, a weighting process in terms of their respective number of hectares relative to contribution to their Gross Revenue was made. From the total Gross Product Income of all the crops, their respective farm contributions were deducted to arrive at Gross Farm Income. From the latter relevant average fixed costs such as depreciation, labour, insurance, etc. were deducted to arrive at Net Farm Income. To arrive at Net income interest on land, interest on capital as well as Management Fees were deducted. Average figures were also used in this instance.

To summarise, the following steps are needed to specify the complete farm budget:

Step 1 – Individual Crop Gross Margins

Step 2 – Crop gross margin used to calculate a Farm Gross Margin

Step 3 – Deduct Fixed costs to arrive at Net Farm Income

Step 4 – Deduct Interest and Management fee to arrive at Net Income

At this stage, steps 1 and 2 have been described. In the following sections the calculation of the fixed cost elements, interest and management fees are explained.

Capital Investment

From surveys in the area and discussions with industry role players it was possible to draw up a budget of the capital investment on a typical mixed crop farm. Table 6-5 presents the values per hectare and the depreciation period applied to calculate depreciation per annum.

TABLE 6-5: REPRESENTATIVE CAPITAL INVESTMENT ON A PER-UNIT BASIS (R/HA)

Item	Capital Investment per hectare (Rand)	Depreciation period (Years)	Depreciation per annum (Rand)
Sheds	621	50	12.42
Pack-house	14906	20	745.34
Refrigeration	1366	15	91.10
Tractors	6956	8	869.57
Implements	1552	10	155.28
Bulk Water	1863	80	23.39
supply	1242	8	155.28
Vehicles	124	20	6.21
Loose tools			
Total	28630		2058.49

It must be emphasised that these figures are average, they tend to be more for smaller units and lower for larger units.

Fixed Costs:

From information received, Table 6-6 below was drawn up to represent the fixed costs from the different crops as used in the regional farm budget.

TABLE 6-6: REPRESENTATIVE FIXED COSTS FOR VARIOUS CROPS (R/HA)

	Avocados	Bananas	Citrus	Mangoes	Tomatoes	Average
Depreciation	2058	2058	2058	2058	2058	2058
Labour	3327	5132	3552	3055	5926	4127
Insurance	1000	1000	1000	1000	1250	1056
Repairs & Maintenance	1798	662	2415	2415	2812	2299
Administration	925	855	925	925	1750	1103
Fuel & Electricity	1514	1091	2612	2743	2251	2327
Sundry	663	843	685	636	1103	783

It must be emphasised that these costs were received from farmers who were asked to allocate them to a crop and then converted by the consultants to a figure per hectare.

Interest on Capital

The interest was calculated on the capital investment as depicted in Table 6-7 as R28 630 per hectare at 5% real interest rate.

Interest on capital: R28 630 x 5% = R1 432/ha

Interest on Land

As explained a value for non developed irrigation potential land was determined at R3 500 per hectare at a rate of 5% were calculated

Interest on land: R3 500 x 5% = R175/ha

Management fee

The farm units in the study area varies considerable in size from very big commercial companies to smallish family enterprises with a developing small farmer component also present

As a weighted average of the management fees appropriate to all the farms in the areas it was decided to use a figure of R3500/ha.

TABLE 6-7: CONSOLIDATED FARM BUDGET

		Avocados	Bananas	Citrus	Mangoes	Tomatoes	TOTAL
Hectares	ha	2 481	70	8 603	2 830	3 888	17 872
Product Gross Margin	***R/ha***	***24 797.60***	***17 923.01***	***25 094.17***	***19 179.70***	***31 626.36***	***25 509.42***
Less		***11 284.66***	***11 641.22***	***13 248.21***	***12 832.16***	***17 150.19***	***13 752.32***
Depreciation	R/ha	2 058.49	2 058.49	2 058.49	2 058.49	2 058.49	2 058.49
Labour	R/ha	3 327.17	5 131.82	3 552.05	3 055.10	5 926.09	3 964.79
Insurance	R/ha	1 000.00	1 000.00	1 000.00	1 000.00	1 250.00	1 054.39
Repair and maintenance	R/ha	1 797.71	661.82	2 415.43	2 415.43	2 812.00	2 409.08
Administration Cost	R/ha	925	855	925	925	1 750.00	1 104.20
Fuel and Electricity	R/ha	1 513.57	1 090.91	2 612.04	2 742.64	2 251.00	2 395.73
Sundry	R/ha	662.72	843.18	685.2	635.51	1 102.61	765.64
Net Farm Income	***R/ha***	***13 512.94***	***6 281.79***	***11 845.96***	***6 347.53***	***14 476.17***	***11 757.11***
Less		***5 106.68***	***5 106.68***	***5 106.68***	***5 106.68***	***5 106.68***	***5 106.68***
Interest on Land	R/ha	175	175	175	175	175	175
Interest on Capital	R/ha	1 431.68	1 431.68	1 431.68	1 431.68	1 431.68	1431.68
Management Fee	R/ha	3 500.00	3 500.00	3 500.00	3 500.00	3 500.00	3500.00
Net Income	***R/ha***	***8 406.26***	***1 175.11***	***6 739.28***	***1 240.86***	***9 369.49***	***6 650.43***

As can be seen from Table 6.7, the Net Income for the regional farm is R6 650 per hectare. Firstly this variable is an important parameter in determining the value of irrigated land as well as the economic value of irrigation water.

Secondly, as already mentioned earlier, farm crop budgets contain information on water requirements, among other things, that forms exogenous data supplied to the linear programming model that forms an important step in determining the value of water. The determination of the economic value of irrigation water will be discussed in subsequent chapters.

6.4 Linear Programme Formulation And Exercising

Once the enterprise budget for an aggregate farm was produced, this formed the prime input to the linear programme, which was formulated as set out in Chapter 4.

In broad principle, the LP is exercised by allowing the full amount of water available to be used, and systematically reducing this amount creating greater and greater degrees of shortage. At each change of available water, the LP calculates the shadow price of water under these conditions. These shadow prices represent the value of water for the particular amount used, and when gathered together and presented as a schedule they constitute the water demand schedule for the farm.

The LP was formulated using What's Best! from Lindo Systems on an Excel spreadsheet, and a portion of the tableu is shown in Table 6.8 below.

TABLE 6-8: EXCERPT FROM LP TABLEAU FOR AGRICULTURAL WATER

DATA							
Index	**I**	1	2	3	4	5	6
Crop		Avo					
Tree age	**years**	0	1	2	3	4	5
Water coefft.	**m^3/ha**	0	577	1 384	5 767	6 344	6 344
Area planted	**ha**	75	75	75	75	75	75
Min area use	**ha**	75	75	75	75	75	0
Max area use	**ha**	75	75	75	75	75	75
ANALYSIS							
Area allocated	**ha**	75	75	75	75	75	75
Water shadow price	**R/m^3**	0.56					
Upper bound	**m^3**	0					
Lower bound	**m^3**	4 341 080					
RESIDUAL							
Revenue margin	**R/ha**	0	0	10 312	24 824	42 872	56 805
Fixed costs	**R**	383 001	383 001	383 001	383 001	383 001	383 001
Variable cost margin	**R/ha**	31 047	12 948	18 917	26 383	36 140	43 035
Total revenue	**R**	0	0	773 416	1 861 794	3 215 378	4 260 344
Total costs	**R**	2 711 520	1 354 129	1 801 775	2 361 755	3 093 470	3 610 640
Net residual	**R**	-2 711 520	-1 354 129	-1 028 359	-499 962	121 908	649 703
Total net residual	**R**	142 447 198					
CONSTRAINTS							
Total land available	**ha**	18 872					
Total water available	**m^3**	150 908 866					
Profit	**R**	142 447 198	>=	0			
Total land use	**ha**	18 872	=<=	18 872			
Total water use	**m^3**	150 908 866	=<=	150 908 866			
Land allocation		75	=<=	75	=<=	75	
			75	=<=	75	=<=	75
				75	=<=	75	=<=
					75	=<=	75
						75	=<=

The columns represent the different crops, with a separate column for each tree age under consideration. The portion of the tableau shown includes only avocado trees from freshly planted to 5 years old. The blocks of rows show general data such as tree ages, water requirements for each hectare of trees of each age, actual area planted and constraints on areas available to the LP. The block headed Analysis displays the shadow price generated by the LP for each iteration, as well as the upper and lower bounds over which that particular basis is valid. The block headed Residual contains the farm crop budget details, as described earlier. The final block headed Constraints contains the constraints on land and water use which the LP is required to observe.

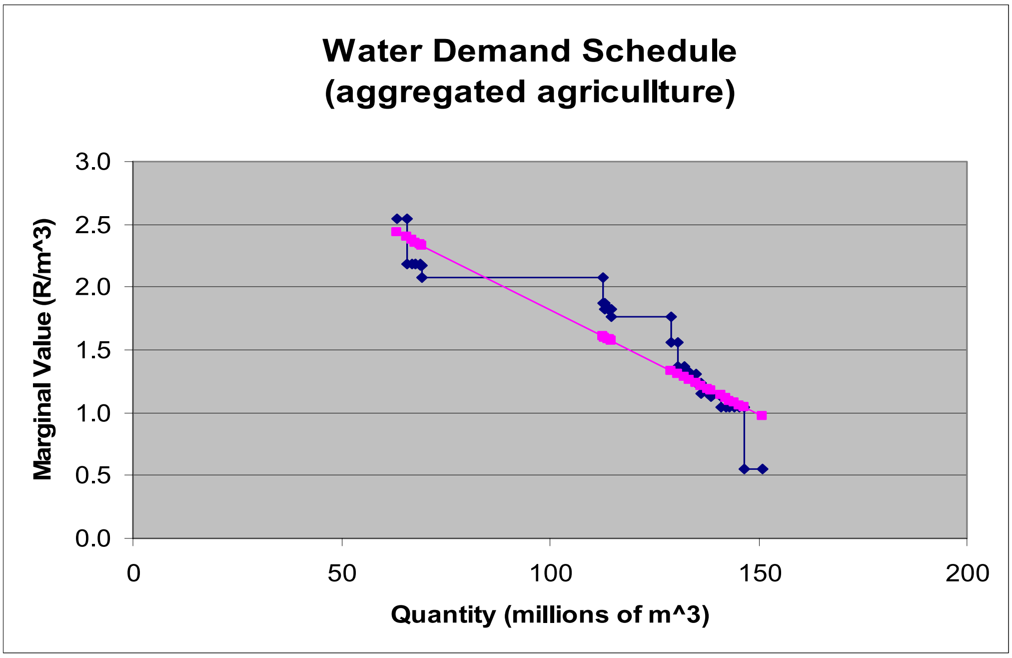
The LP exercise is started by allowing the full amount of water available to be used. Under these conditions there is no water shortage and the shadow price returned is zero. Water use is then systematically constrained and at each iteration of the LP a new shadow price is generated which is relevant to the degree of water shortage being experienced. The selection of the starting point for each new iteration is aided by consideration of the upper and lower bounds which are returned by the LP together with the shadow price.

These results are gathered together to synthesise a water demand schedule, as will be seen in section 6.5. This schedule demonstrates the stepped appearance which is characteristic of this iterative approach to using the LP. In addition to this schedule, a linear form was produced using linear regression to facilitate presenting this information to the NSP model and this is also shown on the diagram in section 6.5.

6.5 RESULTS

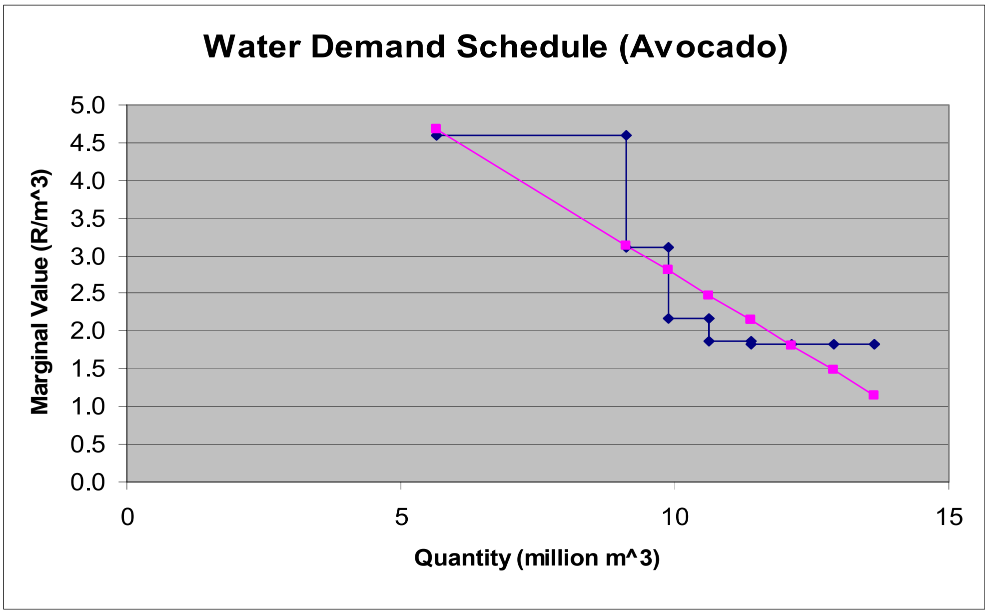
6.5.1 Linear Programme

The water demand schedule was derived by regarding the whole of the study area as a single farm containing the five crops under consideration, in the proportions in which they were found to be present. The marginal value of water will be seen to vary from some R0.50 per m^3 to some R2.50 per m^3.

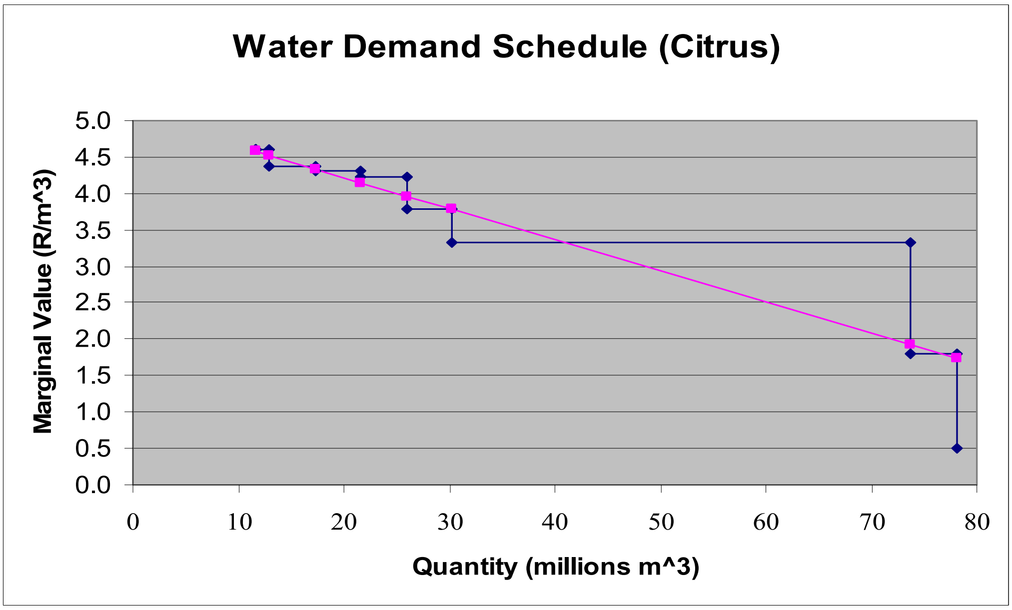


Because the farm budgets assembled for this exercise exhibit different water usage patterns for each age of tree, it is also possible to see the individual water demand schedules for each crop. This is done by exercising the LP in the manner described above for each crop on its own.

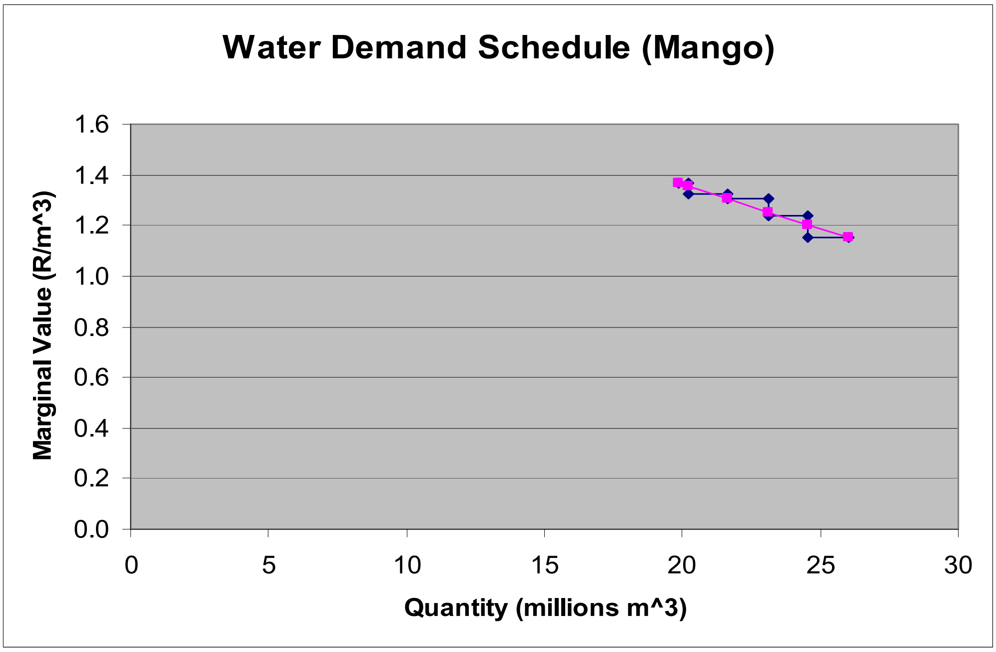
The results are shown on the diagrams which follow.



The diagram above and that below show the demand schedules for avocados and citrus alone. It is of note that the shadow prices for these two crops alone are both greater than those demonstrated by the aggregated. The implication is that these two crops are more efficient water users than the others. However, it must be born in mind that both of these crops are export intensive and have higher margins than the others, and that this contributes towards their higher shadow prices.



The shadow prices of mangoes are less than those of the aggregate farm, and this is also consistent with the margins generated by these crops.



As in the case of mangoes, the water demand schedule demonstrates lower range of shadow prices than those associated with the aggregate farm, again a reflection of the lower margins associated with this crop.

Of greater note in this instance, however, is the unconvincing shape of the water demand schedule for bananas, as it is largely flat. This stems from the fact that the farm crop data available for bananas did not demonstrate any change in water use patterns for trees of different ages after they passed their first year.

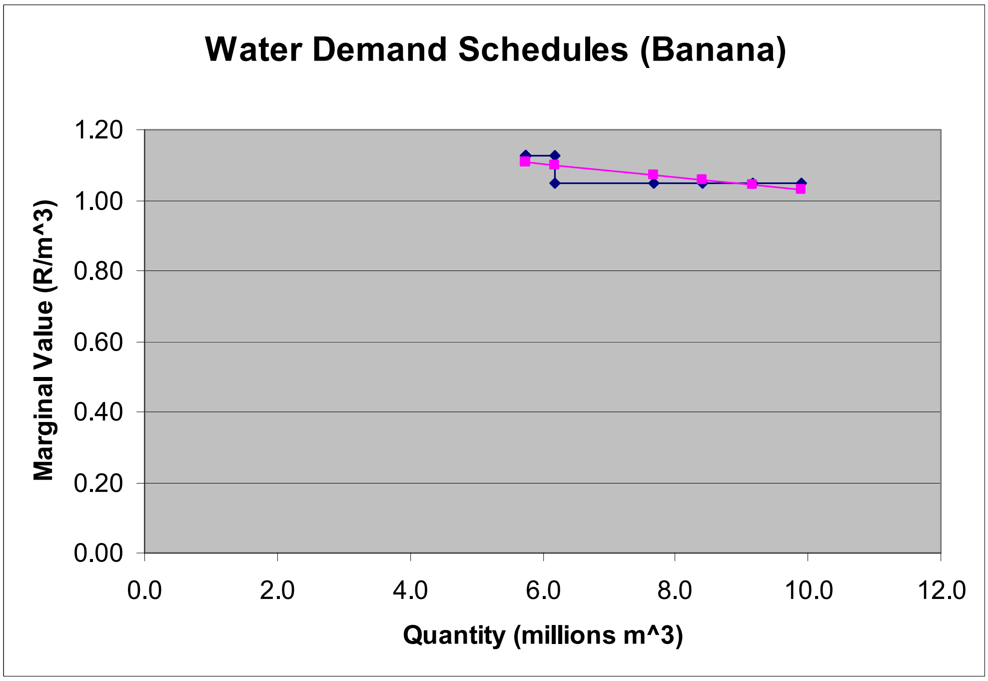


Table 6-9 below summarises the agricultural water usage, prices and costs for different crops. The table shows the economic price of water as revealed by the demand schedule, i.e. the price which would be current if there were a market for water. Thus at any quantity demanded, the price less the cost of providing gives the economic value of the water at that level of delivery.

TABLE 6-9: CURRENT AGRICULTURAL WATER PRICE, VALUE AND COSTS

Crop	Water Use Mm^3	Price R/m^3	Cost R/m^3	Value R/m^3
Avocados	13.6	1.15	0.109	1.04
Bananas	9.9	1.05	0.109	0.94
Citrus	80.7	1.73	0.109	1.62
Mangoes	26.9	1.15	0.109	1.04

6.5.2 6.5.2 Calculation of Water Rent

To provide a check for the value of water for the aggregate farm provided by exercising the linear programme, the rental value of water was calculated by considering the value of the land which represents a return to water.

From the calculation in Table 6.4, depicting a representative farm, it appears that the Net income per hectare is R6 153.80. As already explained in 6.2 the value of the land will be calculated using the formula:

$$\text{Value of land} = \frac{\text{Net Income}}{\text{Interest Rate}}$$

In calculating the Interest Rate an average bond rate of 10% was assumed, plus 2% for risk, giving a total of 12%, divided by the Average Product Inflation Rate experienced by farmers.

Using an this interest rate, we get:

$$\text{Value of land} = \frac{\text{Net Income}}{\text{Interest Rate}} = \frac{\text{R6 650.43}}{12\%} = \text{R55 420}$$

This value of developed land is somewhat high, but nevertheless consistent with market values for such land. The value or undeveloped irrigable land was determined by telephone calls to a number of estate agents and a figure of R3500/ha seems to be a fair value.

The Rental Value or the water (purchase price) is then determined by subtracting the value of dry land from the value of the land:

Value of land	=	R55 420/ha
Value of dry land	=	R3 500/ha
Rental value of water	=	R51 920/ha

As this represents the Present Rental Value of the water, it is necessary to annualise the amount to a yearly value.

The fact that the orchard crops used in the analysis have different lifespans and that the tomatoes is planted on a cyclic basis, makes it necessary to use a relative subjective method to arrive at a period to be used in the calculation. The following table highlights this problem

TABLE 6-10: LIFESPAN OF DIFFERENT CROPS

Crop	Average Orchard Lifespan	Percentage distribution in Representative Farm
Avocados	±30 years	8.31%
Bananas	11 years	8.74%
Citrus	25 years	45.63%
Mangoes	20 years	15%
Tomatoes	Repeat crop every 15 months	22.32%

Using the distribution of the different crops in the representative farm and the crop lifespans, an average period was calculated and used to annualise the rental value. A period of 17.9 years was used.

Using this period, the rental value of R51 920/ha was annualised to give a value of R6 404/ha. Dividing this value by the average water use of 7996 m^3/ha gives the average value of water as R0.8/m^3.

This value for water is consistent with the range of values developed by exercising the LP.

6.6 CONCLUSIONS

The linear programming approach used in this chapter to develop water demand schedules for agricultural water use has provided schedules which are consistent with existing norms, and which delivers results consistent with other exercises in this field. Some detail is lost in linearising the schedules, but this is necessary in order to be able to present them to the NSP model in chapter 10, and it also provides some smoothing of the intrinsically lumpy curves.

The linear program was successful in deriving water demand schedules for individual crops as well as for aggregated agriculture. However, it must be remembered that these remain modelled results, and their use for decision making must be accompanied by an understanding of the assumptions underlying the model and a careful interpretation of the results

In the next chapter, water demand schedules for forestry will be developed, using as combination of enterprise budgets and water production functions.

7 FORESTRY WATER

7.1 INTRODUCTION

Commercial forestry plantations have been classified as water run-off reduction activities. It is therefore a highly regulated activity and before any new or in some cases even replanting is allowed, the landowner or producer must apply to the Department of Water Affairs and Forestry for a license. This is normally only allocated after a proper impact assessment has been done taking into consideration the environmental impacts, water demands at present and in future in the catchment as well as impacts on the communities. It is therefore clear that it is not only market and climatic conditions that dictates afforestation, but also environmental and human needs.

7.2 OVERVIEW

The Letaba catchment, and specifically the Magoebaskloof area in the Groot Letaba, is ideally suited for afforestation. The rainfall in the upper reaches of the Groot Letaba varies between 832 mm to 1 200 mm average per annum. The area is frost-free and the soils relatively deep. DWAF regulates the afforested area and no new permits will be issued because this area is also the water supply areas of the Ebenaezer and Tzaneen dams, the life blood of agriculture in the area. As stated in chapter 2 the total water provision situation has been the subject of a number of studies and will therefore not be repeated here.

The area afforested is ± 45 000 ha in the Groot Letaba catchment and ± 4 300 ha in the Klein/Middle Letaba catchment. Roughly 60% is planted to Gum and 40% to Pine. It is interesting to note that the present empirical models used by DWAF to predict flow reductions was also tested and refined on the Westfalia estate near Tzaneen. Using these empirical models (the Scott/Smith models), the total reduction in the Groot Letaba causes of 9.21% or 35.1 x 10^6 m^3 close to the 35 Mm^3 quoted in the National Water Resource Strategy. For the Klein/Middle Letaba the reduction comes to 0.8% or 1.2 x 10^6 m^3 close to 1 Mm^3 stated in the National Water Resource Strategy.

The modelling approach adopted in this section of the study was to use forestry production budgets as the basis. As mentioned in Chapter 4, it did not prove possible to compile budgets which reflected the sensitivity of trees to changes in water availability, so use was made of crop water production functions based on work done by Dye and Smith (2003) in order to develop full demand schedules from the forestry budgets available.

7.3 PRODUCTION BUDGETS

Due to the sensitivity and confidentiality of financial information within the forestry industry, Forestry Economics Services in Pietermaritzburg was contacted in order to obtain relevant data upon which production budgets could be built. After consultation with Forestry Economic Services the data available for 2002 in Mpumalanga North was judged to fit the Letaba Catchment area the best and these data were acquired and used as proxy for afforestation in the catchment.

In order to understand the production budget that was developed, it is necessary to explain the methodology followed in the forestry industry to determine profits and losses. As a plantation is a long-term project (in the case of pine up to 28 years and for gum between 13-21 years), it is necessary for strict accounts of costs to be maintained, as cash is only generated at the end of the period when the plantation is harvested and the wood sold.

The annual income is therefore based on a "mean annual increment" which is measured in tons/hectare/year, multiplied by the average price per ton received for wood in that specific year This is converted to a so-called average net standing price.

The following framework encapsulates the procedure to arrive at the average net standing price and the annual profit potential if the mean annual increment (MAI) is sold.

Annual Sustainable Profit Per Hectare If M.A.I. Is Felled And Sold	
Timber delivered to Buyer Timber sold Free on Rail or Depot	R/ton R/ton
AVERAGE PRICE RECEIVED Less: Transport costs	R/ton R/ton
NET PRICE ON ROADSIDE Timber sold on roadside	R/ton R/ton
AVERAGE PRICE ON ROADSIDE Less: Harvesting costs	R/ton R/ton
NET STANDING PRICE Standing sales	R/ton R/ton
AVERAGE STANDING PRICE PER TON	R/ton
Multiplied by: Sustainable M.A.I.	Ton/ha/yr
ANNUAL STANDING INCOME Add: Sales of other forest products Less: Establishment costs Tending costs Forest Protecting costs	R/ha R/ha R/ha R/ha R/ha
GROSS MARGIN Less: Overhead costs	R/ha R/ha
ANNUAL PROFIT POTENTIAL IF M.A.I. IS SOLD	R/ha

Source: Forestry Association

It was decided to use pine and long term gum budgets in the calculation. The reason for deciding on long term gum is the optimal growing conditions prevailing in the Groot Letaba that favours long term gum. Although the tendency in the Mpumalanga North region is now to favour short term gum in the new plantings, this accounts for a relatively small proportion of the gum grown in the catchment, and the impact will only be felt in the budgets when the rotation age is reached and the trees are harvested.

In Table 7.1 the calculation of gross margin is presented as obtained from Forestry Economic Services, with the exception of the Mean Annual Increment (MAI). In the case of the MAI figures obtained from sources in the Catchment were used; these figures are 18.75 and 23.07 and are slightly higher than the average for Mpumalanga North contained in the data from Forestry Economic Services.

TABLE 7-1 BUDGET TO DETERMINE ANNUAL PROFIT FOR PINE AND LONG TERM GUM IN THE LETABA CATCHMENT

		Pine	Gum
Income			
Average standing price	R/Ton	100.04	71.52
Sustainable MAI	Ton/ha/yr	18.75	23.07
Annual Standing Income	R/ha	1875.75	1649.97
Other Forest Products	R/ha	3.59	0.35
Total Annual Income	R/ha	1875.75	1649.97
Costs			
Establishment Costs	R/ha	63.07	118.13
Tending Costs	R/ha	118.64	128.02
Forest Protection Costs	R/ha	222.1	222.1
Total Variable Costs	R/ha	403.81	468.24
Gross Margin	R/ha	1475.53	1182.08
Overhead Costs	R/ha	674.77	674.77
Annual Profit Potential if MAI is sold	**R/ha**	**800.76**	**507.31**
Less – Interest on Land		144.55	144.55
– Interest on Capital		166.60	164.60
Net Income	**R/ha**	**489.61**	**198.16**
Water Use	m^3/ha	740.8	732.6
Value of Water	**R/m^3**	**0.66**	**0.27**

Source: Forestry Association

Establishment costs include land preparation, planting, blanking, and fertilising.

Tending costs include weed control, pruning, clearing, storm and wind and fire damage, thinning, forest protection and tree insurance, conservation and environmental management.

Overhead cost includes hand-tools, road maintenance, building maintenance, administration and community development. It must be emphasised that the establishment costs per hectare planted are phased over the expected lifetime of the plantation. In 2002 the actual establishment cost per hectare for pine planted was R1 759,66 and the expected average rotation age 27.9 years. Dividing these two values give the value of R63,07 per ha used in the pine budget. In a similar fashion, the establishment costs for gum in the budget was calculated from a cost of gum planted of R2 315,39 and an expected rotation age of 19.6 years

Other costs are average values calculated per hectare over the total hectares cultivated.

The net income includes the fixed costs associated with the enterprise, namely the interest on land and interest on capital.

The interest on land and capital are calculated as indicated in the table below. The capital value of land (R2 891) is taken from the data from Forestry Economic services, and represents the dry-land value of the land.. The other capital value (R3 332) is the capital expenditure other than that on land.

	Capital value (R/ha)	Discount rate	Interest (R/a)	
Interest on Land				
(pine)	R 2 891,00	5%	144,55	
(gum)	R 2 891,00	5%		144,55
Interest on Capital				
(pine)	R 3 332,00	5%	166,60	
(gum)	R 3 292,00	5%		164,60

The amount of water used by pine and gums, expressed in terms of stream-flow reduction, is derived by dividing the stream-flow reduction for each timber type by the number of hectares planted, as indicated in the table below. The data is as derived in Chapter 5, Water Balance.

	Area planted	Streamflow Reduction	
	ha	Mm^3	m^3/ha
Pine	19935	14.768	740.8
Gum	29365	21.513	732.6

Once the profit potential and streamflow reduction are established, it is possible to arrive at a value for the value of the water used, as shown in Table 7.1 above.

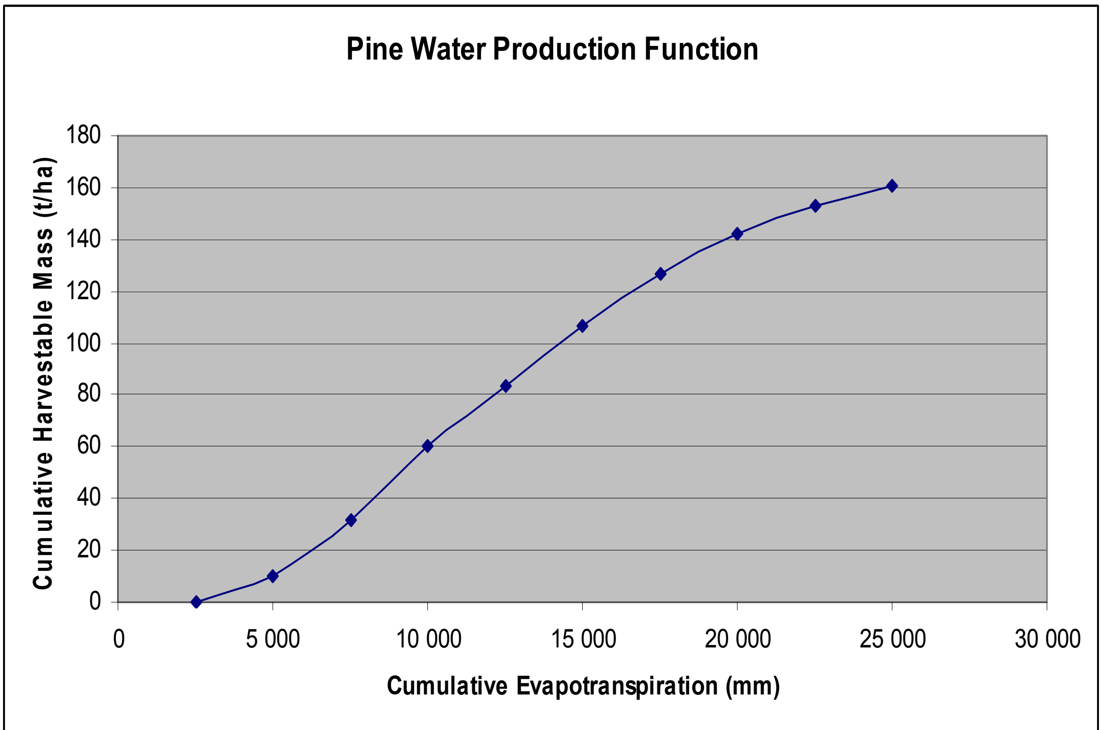
This value of water, representing the value of water at the present level of streamflow reduction, provides only one point on the water demand schedule which is to be generated. In order to estimate more values as the level of streamflow reduction varies from the present level, a knowledge of how production, and hence profit, varies with change in available water level. This final step in the synthesis is achieved by consideration of the water production functions for pine and gum.

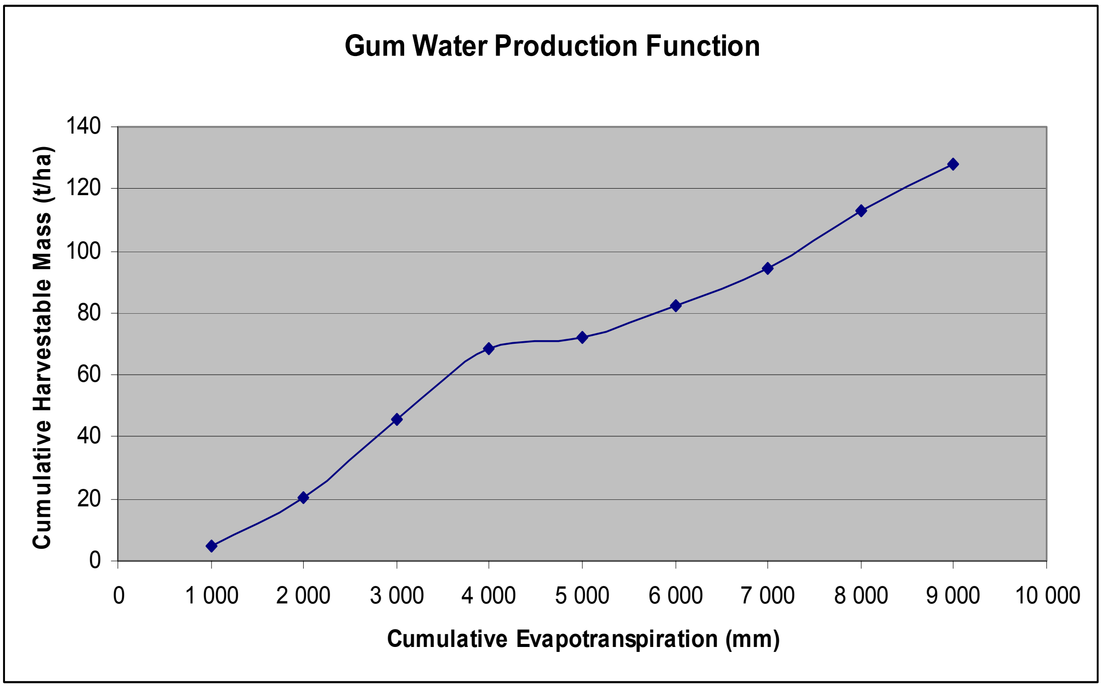
It is interesting at this point to consider water values obtained by Tewari (2003) in KwaZulu-Natal. Using a marginal value product approach and considering streamflow reduction, Tewari gets an annual value of water for gum of R3,42/m^3, and R1,79/m^3 for pine. It must be borne in mind that the marginal value product method used by Tewari estimates water value before other costs been deducted, whereas the residual value method, as used here, estimates water value after other costs have been deducted and results in a lower value for water. These results can therefore not be compared with the values of R0,27/m^3 for gum, and R0,66/m^3 for pine estimated in this study. What is notable, however, in Tewari's values, is the great discrepancy in the water values for pine and gum, with the value for gum being roughly twice that for pine. In this study the situation is reversed. This could in some extent be attributed to the fact that the 2002 production budgets for gum show a very low annual profit potential compared with pine, for very similar values of streamflow reduction.

7.4 WATER PRODUCTION FUNCTIONS

Water production functions were developed by Dye and Smith (2003) for pine and eucalypts in the Kwa-Zulu Natal area. Assuming that for similar mean annual increments, water production functions for these trees would be similar, the curves of Dye and Smith were interpolated to reflect the MAIs of 18,75 and 23 for pine and gum respectively in the Letaba catchment. These curves, related to cumulative evapotranspiration are reflected below.

Using these curves it is possible to estimate the marginal change in production arising from a change in available water and to put a value on this using the forestry production budgets. The resulting values represents the marginal values of the quantities of water which give rise to the change in production.





The process of deriving water demand schedules from these production functions is explained in Section 7.5 below.

7.5 Demand Schedules

The steps involved in constructing the water demand schedule are as follows:

- Starting with the existing level of streamflow reduction (which represents the water used by the trees) and the value of water at that level, a lesser level of streamflow reduction is postulated.
- From the appropriate water production functions, an output of timber is calculated at the level of water use represented by this new streamflow reduction, and a value for this quantity of production is calculated.
- From these figures, a marginal change in streamflow reduction and a marginal change in water value are calculated. These two values represent the next point on the water demand schedule.
- The process is continued until the desired range of marginal water values and streamflow reductions have been calculated.

The resulting schedules were linearised using linear regression, both to smooth the raw curves and to be able to present the data in a form which can be presented to the NSP model discussed in chapter 10. The results are depicted in figure 7.1.

From these curves it can be seen that the value of water for pine ranges between R0,60/m^3 to R0,80/m^3. At 5% pa this would give rise to a capitalised value of some R5,70 to R7,60 (5% is used for this calculation to allow comparison with agricultural water).

Similarly for gum, the value of water ranges between R0.25/m^3 to R0.37/m^3. This represents a capitalised value of some R1.41 to R2.09 (again capitalised at 5%).

The annual and capitalised values of water at the present levels of streamflow reduction are given in Table 7.2 below.

TABLE 7-2: FORESTRY WATER VALUES USING STREAM FLOW REDUCTION VOLUMES

	Streamflow Reduction	Annual Values	Capitalised Values
	Mm^3	R/m³/annum	R/m³
Gum	21.513	0,27	1,56
Pine	14.768	0,66	6,35

The disparity between the figures for pine and gum give rise for some concern, but this can be attributed to the fact that for the year in which the data was gathered, income from gum was abnormally low.

FIGURE 7-1: Linearised Pine Water Demand Schedule

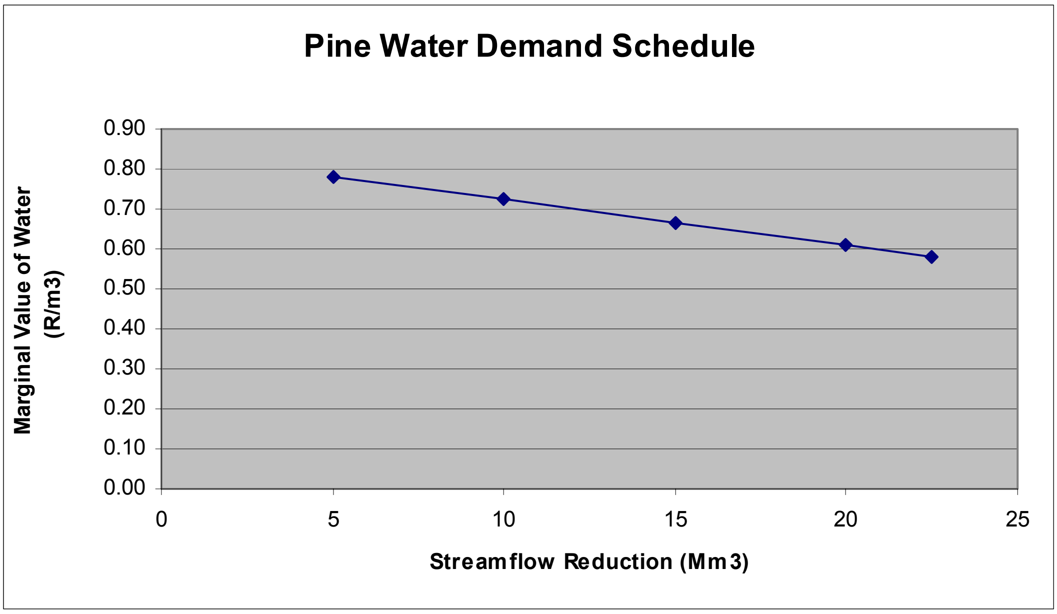
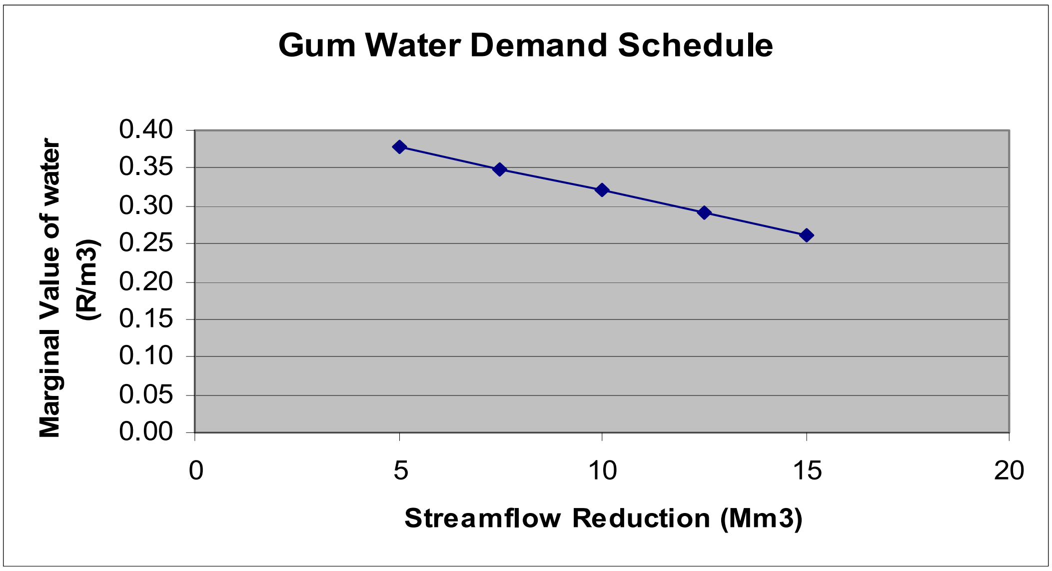


FIGURE 7-2: Linearised Gum Water Demand Schedule



7.6 WATER COSTS

As previously mentioned, DWAF now operates on a licensing system for all water users. Every water user has been registered and pays a fee according to the volume of water used. At the moment of the writing of this report the registration process has been completed but the verification process has only started. At the moment afforestation are paying a fee based on the water reduction calculated by using the Scott/Smith formula. The water run-off reduction is therefore a proxy for the water use of commercial forestry plantation.

The cost of incurring this run-off reduction is regarded as a cost of water to commercial forestry, and the tariff they pay is regarded as a cost of water. Details are given below in Table 7.3.

TABLE 7-3: WATER PAYMENTS BY FORESTRY IN THE LETABA

Sub-Catchment	Tariff R/m^3	Water Reduction	Amount Paid
		Mm^3	
Groot Letaba	0,0098	35.1	R343 980
Klein/Middle Letaba	0,0098	1.2	R 11 760
Total		**36.3**	**R355 740**

Note: The tariff used here is the official 2003/2004 tariff.

These costs have not been embodied in the enterprise budgets discussed above that were used to develop the water demand schedules. To remain consistent with the calculation of water values in other user sectors, and to facilitate the presentation of this information to the NSP model, costs and values are developed separately.

7.7 CONCLUSION

Although great difficulty was experienced in obtaining suitable data for water production functions for forestry, the latest enterprise budgets (2002) were available from Forestry Economic Services and these budgets form the underpinning of the exercise. As in the case of agriculture, the water demand schedules have been linearised to enable them to be smoothed and carried forward into the NSP model. The disparity between the figures for pine and gum give rise for some concern, but this can be attributed to the fact that for the year in which the data was gathered, income from gum was abnormally low.

8 MUNICIPAL WATER

8.1 INTRODUCTION AND BACKGROUND

In this section, a specific methodology will be described and exercised for the determination of the economic value of municipal water in the Letaba Catchment Area.

In addition to the introduction, this section consists of 7 parts. Firstly, an overview to the current water situation in South Africa and the Letaba Catchment Area is presented. Secondly, there is a qualitative description of industrial and non-municipal water uses. Thirdly, the methodology used for the determination of the economic value of municipal water is described in detail. The fourth part presents the results obtained. The cost of the water consumed is revealed in the fifth part. A comparison of the cost and value for an input to the NSP model is presented in the sixth part; thereafter appropriate conclusions are drawn.

Water is a non-market good, private in nature but with great public goodness associated with it. Attaching a value to this water will assist water managers with tariff setting for redistribution of water resources, the determination of socially optimal water resources and the construction of policy interventions over time. To achieve this it is necessary to attach an economic value to water. Studies undertaken in Australia (Thomas & Syme, 1988) and South Africa (Veck & Bill, 2000) approached the problem of estimating the demand for municipal water utilizing a Contingent Valuation Methodology (CVM). The information gathered from Contingent Valuation surveys, representing users' willingness-to-pay for water, is used to synthesise water demand schedules from which the economic value of water can be derived. This approach forms the basis of this study

The survey samples for this study area were undertaken in the municipal areas of Polokwane and Giyani. Polokwane serves as a proxy for all municipal water users in the middle and high income group and Giyani as a proxy for all low income groups.

The overall approach followed can briefly be summarised as follows:

Utilizing the individual samples, demand schedules for all income groups are derived for an average household for monthly water usage. Utilizing the 2001 population census an aggregated demand schedule, per income group, is derived on an annual basis. From these demand schedules a total aggregated demand schedule for municipal water is derived. From the analysis of this aggregated demand schedule the consumer surplus and total economic value for municipal water is calculated. This value is then compared with the cost of the water.

8.2 OVERVIEW

South Africa is a drought-prone, water poor region and water shortages will influence economic development. As water scarcity increases, the need to manage water, particularly municipal water, as a national asset and for overall social benefit becomes imperative. This section deals briefly with the current situation pertaining to municipal water services and requirements in the Letaba Catchment Area.

Municipal water use consists of municipal and industrial use. Consumptive use of water for municipal purposes in the Letaba Study Area, is less than 0.7% percent of total municipal water consumption in South Africa.

Municipal water use in the Letaba Catchment area is given in Table 8-1. It will be seen that industrial water use is 4% of the total municipal use, whereas municipal use is 96%.

TABLE 8-1: MUNICIPAL WATER IN THE LETABA CATCHMENT AREA, [MILLIONS KILOLITERS PER ANNUM, 2000]

	KL	%
Municipal water	25.32	96%
Industrial	0.95	4%
Total	**26.57**	**100%**

Source: DWAF, National Water Resource Strategy (2003)

The industrial water usage is shown in Table 8-2.

TABLE 8-2: LETABA CATCHMENT INDUSTRIAL WATER USE, MM^3 (2000)

Addington Farm-Industry	0.048
Letaba Farmers Club	0.011
Koedoe Co-operation	0.1
Letaba Citrus Processors	0.646
Consolidation Citrus Containers	0.025
Maranda Mining Company	0.12
Total	0.95

Source: DWAF, Working Document in Groot Letaba (2001)

The following sections, which look at the economic value of this water, will only derive the value of the municipal water, in accordance with the objectives of this study. This short description of the overall usage of municipal water is presented to put municipal usage in perspective.

8.3 ECONOMIC VALUE OF MUNICIPAL WATER

8.3.1 Introduction

This part consists of five sections in addition to the introduction. The first section provides a background to the economic value of municipal water. The second section provides a detailed discussion upon the method applied in this study, the Contingent Valuation Experiment. The approach used to implement the Contingent Valuation Experiment follows, with results as analysed in the context of the Letaba Catchment Area. Lastly, water demand schedules based on population samples are presented, and these are then aggregated to provide demand schedules for the total Catchment.

8.3.2 Background

As mentioned in Chapter 4 when discussing the modelling approaches, municipal demand is a direct demand and its value would be determined by exploring willingness-to-pay for water by means of a contingent valuation experiment and the reader is reminded that a single survey approach, involving only a contingent valuation survey, is being used.

8.3.3 Contingent Valuation Experiment

Background

In general this method is utilized where market values for a good are not available. The value of water estimated using this technique can be compared with market prices. Over 1000 journal papers have been published using this technique. A major criticism of the technique is that estimates are hypothetical and not actually observed (Pasour et al., 1993).

The Contingent Valuation (CV) experiment is a method to explore the consumers' behaviour to a change in their consumption pattern, for a given change in the price/tariff of water. Findings are based on survey designs that, undertaken as a measure of intention or consumer behaviour in the market, used professional interviewers to conduct personal interviews determined from a representative sample of households. The responses to the surveys is known as contingent values for they establish what consumers will pay, or receive, contingent upon a market being created.

Herbelein and Bishop (1986) have defined contingent values as a measure of behaviour intention, which is measured in relation to market values, actual buying and selling behaviour. The validity of willingness-to-pay measures fits well with the theory because consumers have thousands of repeated experiences buying things; they therefore develop relatively clear ideas of what they would be willing to pay for commodities.

Veck and Bill (2000) suggested "The need for establishing a value base for water is very real, without such values cost-benefit analysis, a major tool in the arsenal of applies economics is rendered suspect. In attempting to pass opinion on public policy matters economics cannot therefore limit itself to goods and services that are allocated via market mechanism but have to consider non-market goods and services as well. This is particularly true when the question of human welfare is being debated, and water resources are very important with respect to this. CV is therefore gaining acceptance as a bona fide approach to the problems of water and human welfare and this is clearly shown in the literature on the subject."

Water management decisions associated with water tariff design and water payment strategies can be alleviated if consumers' behaviour with regard to water demand and price is clearly understood. By means of CVM experiment, robust water demand schedules can be generated for different categories of consumers and appropriate price elasticity of demand can be estimated providing such an understanding. The next section describes how such a CVM experiment is conducted.

Contingent Valuation Survey

Purpose

The CV experiment sets out to determine how consumers would amend their water consumption patterns when faced by rising water prices. In this exercise water price changes of 50%, 100% and 150% and above the price in place in the year 2002, were postulated.

In attempting to generate water demand schedules by means of a CVM experiment, it is necessary to be effective and to choose suitable samples of participating consumers from different income groups from each geographical area.

Random Sample

In order to determine the behaviour of water users in communities when faced with changes in the water price, a sample of at least 30 respondents were chosen from each income group being surveyed. Giyani was chosen to stand proxy for the low income group, whilst Polokwane represented the middle and high income groups, giving a total of 90+ respondents interviewed.

The respondents were all water users who are currently paying for water, either a flat rate, or with a quantity-based tariff. The respondents were acquainted with the concept of paying for the services that accompany water supply. Each respondent was subjected to one interview eliciting responses that contained information about their water usage profile and water usage patterns. The data was collated and analysed and combined to obtain an average demand schedule for different income groups.

Approach

Two approaches to CV Experiment are possible. There is the single-survey approach, which is applied in this study, and the two survey approach favoured by Veck and Bill (2000), and Thomas and Syme (1988). This two survey approach employs one survey to determine a water usage profile, followed after a time interval by the CV survey. Timing is very important as the mood of co-operation from the respondents between the surveys can change or the respondent might have moved or their behaviour pattern can change between surveys. By contrast, the one survey approach, which only entails the utilisation of the CV approach, is more cost effective, less time consuming and does not rely on the ongoing co-operation of the respondents.

The one-pass approach embodies a survey that is based on the water bill itself and the variation in the water bill stemming from any change in the water tariff. This data is gathered in one interaction with the respondent.

As this approach provided the data required and did not jeopardise the integrity of the exercise, its use is considered justifiable in this instance. Below is a description of the CV Survey as carried out in the study area.

Contingent Valuation Survey: Letaba Catchment

Random Sample

This specific survey was carried out by Marketing Surveys and Statistical Analysis (MSSA).

The dominant characteristic of the sample is that it was undertaken using a method commonly known as Quota-sampling. Interviewers were given definite quotas of persons in different social classes, different regions and were then instructed to obtain the required number of interviews to fill each quota. Quota-sampling interviews are undertaken on a personal basis between researchers and respondents.

The study was based on 110 samples of a target population of 1,2 million people. Some main factors that played a role in this study were income and culture. Data were collected by means of one-on-one interviews with respondents. The survey samples for this study area were undertaken in the municipal areas of Polokwane and Giyani. Polokwane was chosen to serve as a proxy for all municipal water users in the middle and high income group and Giyani as a proxy for all low income groups. The samples were constituted as follows, based on population figures taken from the 2001 population census:

- 30 samples from the lower income group representing 25 886 low income households in Giyani which account for approximately 57% of total population,
- 39 samples from the middle income group representing 23 081 middle income households in Polokwane which account for approximately 16% of total population,
- 41 samples from the high income group representing 39 415 high income households in Polokwane which account for approximately 30% of total population..

In being greater than or equal to 30, the sample sizes take cognisance of the central limit theorem theory which means that they are large enough for the sampling distribution of the mean to be normal and the samples to be representative of the populations from which they are drawn.

Results and Discussions

In this section the results of the analysis of the Contingent Valuation Survey in the Letaba Catchment are presented. To provide the maximum data in the clearest fashion, recourse will be made to tables and graphical presentations of these results with discussion in narrative form.

For the purposes of this study, income levels are defined as follows:

- Low income group: below R6 000 per annum
- Middle income group: R6 000- R12 000
- High income group: R12 000 and above.

The following figures and tables present the results of the analysis of the survey, per household per income group on a monthly basis: (See Appendix 2 for examples of the questionnaire and their detailed analysis.)

- Table 8-3: Average monthly water usage
- Table 8-4: Average monthly water bill
- Figure 8-1: Effect of the increase in the price of water .

TABLE 8-3 : AVERAGE MONTHLY WATER USAGE PER HOUSEHOLD

	Low Income	**Middle Income**	**High Income**
Average water usage [kilolitres per month]	47	54	66

Table 8.3 shows the average monthly water usage per household in the different income groups in Polokwane, high and middle income, and Giyani, low income, as a proxy for the total water usage for the population in the study area. It should be noted that the term "average water usage" in this context refers to the average water usage for a number of households per income group. This average water usage per household is subject to the following water tariff. In the low income group, which is based on a flat tariff structure, the current tariff is R1,00. For the middle and high income groups, where the tariff is a quantity-based tariff, the current tariff is R5,32 and R5,59 respectively.

It can be seen that there is a 29% increase in the water usage in kilolitres per month from the lowest income group to the highest income group. The differences within Polokwane, i.e. from the middle income group to the high income group is approximately 18%.

TABLE 8-4 : AVERAGE MONTHLY WATER BILL PER HOUSEHOLD

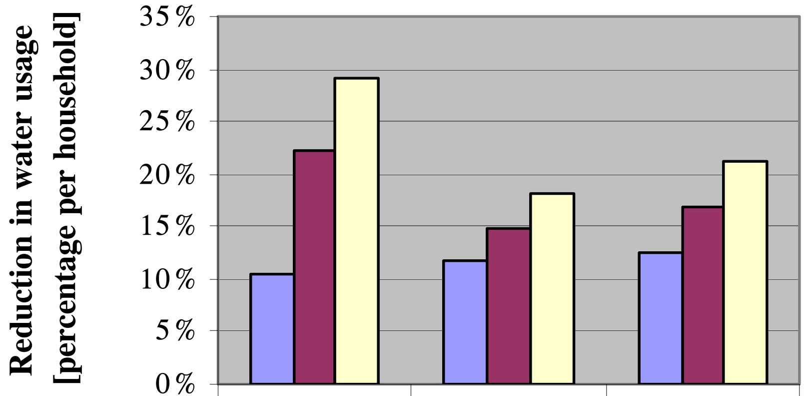
	Low Income	**Middle Income**	**High Income**
Average water usage [Rand per month]	50	245,73	325,61

Table 8-4 is the equivalent average monthly bill for water used in the different income groups in Polokwane and Giyani. There is a disparity in the percentage differences in prices between the different income groups. This arises from the fact that there are different tariff structures in force in the two geographical areas where the surveys were done. Giyani's water tariff (low-income group) is based on a flat rate whereas Polokwane's water tariff (middle and high income groups) is based on quantities actually used.

A pattern of outdoor and indoor water use was determined with regard to the three income levels low, middle and high income. An assumption was made that for urban primary water use the split between indoor and outdoor water use is 30% and 70% respectively. Regarding rural primary water use, the split between indoor and outdoor use is 15% and 85% respectively.

The figure below describes the effect of the price increase of water on the usage pattern of water for the various income groups in the study area.

FIGURE 8-1: EFFECT OF THE INCREASE IN THE PRICE LEVEL OF WATER BY THE VARIOUS INCOME GROUPS AS PERCENTAGE IN AVERAGE WATER USAGE PER HOUSEHOLD



	Low	Middle	High
50 %	11 %	12 %	12 %
100 %	22 %	15 %	17 %
150 %	29 %	18 %	21 %

Income Group

The following observations are pertinent:

- As the price increases, there is a tendency for all income groups to reduce water usage.
- The lower income group, because of their limited disposable income, have to decrease their use of water more as the price level of water increases in comparison to the other income groups.

8.4 DEMAND SCHEDULE

8.4.1 Introduction

A detailed discussion on the derivation of the demand schedule is given below.

The aim is threefold, namely:

- To derive a demand function of water for the Letaba Catchment for various user categories
- To calculate price elasticity of demand for water, in order to determine how responsive water demand is to changes in the tariff

- To present and evaluate results obtained.

In addition to the objective above, a theoretical background follows.

8.4.2 Background

To estimate the economic value of water the demand schedules demonstrating the relationship between the price of water and the volume consumed are constructed below. This exercise has made use of information gathered during the CV surveys, together with information relating to the total quantity of municipal water used in the study area, as revealed by the water balance in Chapter 5.

The study by Gibbons (1986) provides the basis for discussion that follows. In the absence of working markets for water and with the growing conflict over water use, there is a pressing need to understand the underlying economics of water demand to the municipal sector, which is the main user.

More complete demand information is presented in a formal demand schedule for a particular use. With the Contingent Valuation Experiment, enough price and quantity data are available to compile a water demand schedule from which, in turn, estimates can be made of marginal values of the resource use at different quantities demanded as well as the consumer surplus.

8.4.3 Derivation of the Demand Schedule

The classical consumer theory postulates that a consumer's demand function is a function of price and income. The main aim of this section is to derive the municipal water demand schedule based on consumer behaviour as described above.

The demand schedules at a household level, as well as the price elasticity of demand, were determined as follows for each of the income levels:

- The total bill for the particular income group considered was established by summating the water bill of the households within the group at the present price of water. This total bill was divided by the summated quantity of water for the income group considered. Thus the one point on the demand schedule for the specific income group was established, i.e. the total quantity of water used by the group and the average unit price of water was established. This point represented the status-quo position with regard to water usage in a particular income group.
- Similarly, three other points on the demand schedule for the same income group considered were established from the answers to the questions in the CV survey, i.e. when the current price of water was increased by 50%, 100% and 150% and above.
- This information provided four points which together represent the water demand schedule. A linear regression analysis was undertaken to determine the equation of the demand curve for the particular income group considered. This linear representation of the demand

curve is necessary to enable the information to be used in the integrating model as described in Chapter 10.

- The arc elasticity of demand for water was then determined using the formula described below.
- The arc elasticity is the elasticity at the midpoint of a chord that connects two points, A and B, on a demand schedule and is derived as follows:

If Q_1 is the quantity demanded at price P_1 (point A) and Q_2 is the quantity demanded at price P_2 (point B), then the arc elasticity, e_p, is given by:

$$e_p = \{(Q_1 - Q_2) / (Q_1 + Q_2)\} \text{ x } \{(P_1 + P_2) / (P_1 - P_2)\}$$

8.4.4 Elasticity of Demand

The second aim is to calculate the price elasticity of water demand. An "elasticity of demand" for a commodity is defined as the ratio of the proportional change in the quantity demanded to the proportional change in a particular determining factor (e.g. water tariff) of the commodity (e.g. water).

In South Africa, because the price of water has been historically low, large price increases are postulated in this experiment. Experience shown that when small price increases are postulated, the results obtained from the experiment do not yield results that are useful since the change in consumers' behaviour to the price increases are generally muted. Understanding these circumstances of the water price in South Africa, it was appropriate for calculating the arc elasticity (average elasticity) of demand.

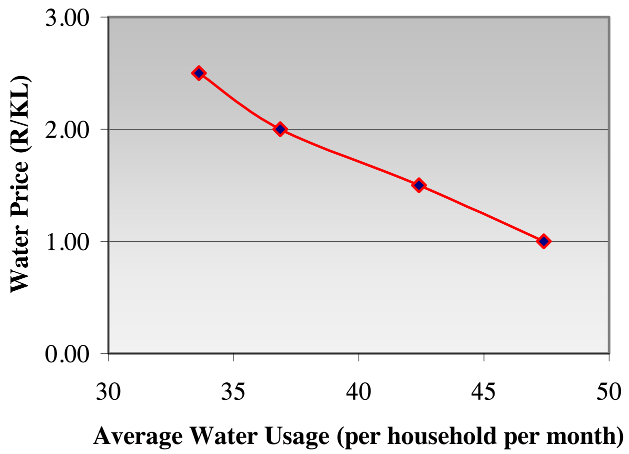
8.4.5 Results of the Survey

The sample elasticity to demand for water and demand schedules for the different income groups, respectively, follows.

Low income

The estimated elasticity for demand for water, the demand schedule derived and applicable statistics are as encapsulated in Figure 8-2:

FIGURE 8-2: MUNICIPAL DEMAND FOR WATER IN THE LOW INCOME GROUP.- GIYANI SURVEY



Elasticity	-0.397

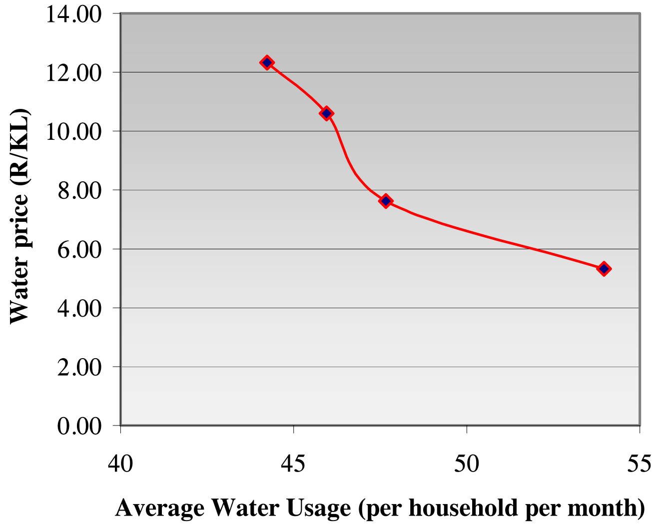
This value indicates that the Lower group in the Letaba Catchment Area is water tariff inelastic and for a 1% increase in tariff, this group will decrease its water consumption by 0.4%. The fact that they will decrease their consumption when the tariff increases is expected from traditional demand. As water is essential for life and it has very few, if any, substitutes, this is to be expected.

The demand schedule derived predicts the trend for the low income sample water consumption. Quantity on the demand schedule above represents the average quantity of water consumption per month per household unit, against the current water tariff for this unit. It can be noticed that the consumption is high in comparison to the other two income groups, medium and high. The reason for this is that in the study area, the low income group has a fixed bill rate. The economic value, which is the area under the graph, is estimated at 65.80 kiloliter per household unit by utilizing sample as proxy to the low income population.

Middle Income Level

The estimated elasticity for demand for water, the demand schedule derived and applicable statistics are shown in Figure 8-3:

FIGURE 8-3: MUNICIPAL DEMAND FOR WATER IN THE MIDDLE INCOME GROUP - POLOKWANE SURVEY



Elasticity	-0.250

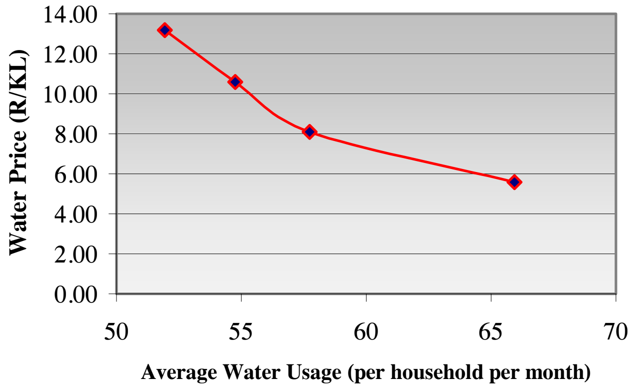
This value indicate that the middle group in the Letaba Catchment Area is water tariff inelastic and for a 1% increase in Tariff, this group will decrease its water consumption by 0.25%.

The demand schedule derived predicts the trend for middle income sample water consumption. Quantity on the demand schedule above represents the average quantity of water consumption per month per household unit against the current water tariff for this unit. It water consumption is more or less the same volume as for the high income level. The reason for this is that in the study area, these income groups have a quantitative bill rate. The economic value, which is the area under the graph, is estimated at R352,40 per household unit by utilizing sample as proxy to the middle income population.

High Income Level

The estimated elasticity for demand for water, the demand schedule derived and applicable statistics are shown in Figure 8-4:

FIGURE 8-4: MUNICIPAL DEMAND FOR WATER IN THE MIDDLE INCOME GROUP.- POLOKWANE SURVEY



Elasticity	-0.294

An elasticity value of –0.29 means that this income group's consumption of water is tariff inelastic. In other words, a 1% change in the tariff will results in less than 1% change in the amount of water consumed. As the tariff increases by 1%, the consumption of water in the high income group will decrease by 0.29%. The demand schedule derived depict a good for the high income group

Quantity on the demand schedule above represents the average quantity of water consumption per household unit against the current price for water for this unit. The economic value, which is the area under the graph, is estimated at R462,80 per household unit by utilizing sample as is.

Table 8-5 below summarises the outcomes to the Contingent Valuation Experiment regarding the elasticity to water demand and demand schedules:

TABLE 8-5: SUMMARY OF SURVEY RESULTS

Income Group	**Elasticity Elasticity**	**R^2**	**Current Water Usage** [KL per month]	**Current Tariff** [R/kl]	**Economic Value** [Rand/household]
High	(0.29)	0,92	66.00	5,59	462,80
Middle	(0.25)	0,89	54.00	5,32	352,40
Low	(0.40)	0,99	47.00	1,00	65,80

- Price elasticity of demand for water in the upper and the middle income groups are almost the same and inline with previous studies. This shows that these income groups have similar mores with regard to water use.
- The estimated price elasticity for water demand in the different income groups demonstrate a trend that, as the disposable income falls, less

water is saved with a 100% price increase. This means that the upper income group can save more water than the other two income groups because they have that water to save, i.e. they may have the propensity to use more water for luxury purposes than the middle and lower groups.

- The results confirm that the high income group use more water than the other income groups demonstrated by the amount of water they save as the price increase, i.e. the elasticity of water demand of this income group are more elastic.
- Further, it can be concluded that the demand schedules derived are good representatives for the specific income groups.

The elasticity of demand for municipal water usage found in the Letaba Catchment Area as detailed above, can be compared with elasticities found in several other international and local studies for municipal water. Table 8-6 presents this summary to previous studies compiled for comparison to results obtained in this current study.

TABLE 8-6: SUMMARY: LITERATURE ON PRICE ELASTICITY OF DEMAND FOR WATER

Researcher/s	Date	Type of Analysis & Location	Elasticity
International			
Howe and Linaweaver	1967	Cross-sectional	-0.7 to -1.57
		USA	
Turnovsky	1969	Cross-sectional	-0.05 to -0.4
		Massachusetts	
Wong	1972	Cross-sectional	-0.26 to -0.82
		Illinois	
Australian Academy of Scientists Technological	1999	Panel data Regression Model	-0.40
		[Low income]	
Thomas and Syme	1979	Contingency Valuation	-0.18
		Perth Australia	
Billings and Agathe	1980	Time Series	-0.39
		Arizona	
Local			
Dockel	1973	Cross-sectional	-0.69
		South Africa	
Conradie	2002	Panel Data Regression Model	-0.47
		[Low income]	
Veck & Bill	1998	Contingency Valuation	-0.17
		South Africa	

It is clear that the results are very compatible and will be observed from the table that the short-run elasticities of demand for total water usage range from –0.05 to –0.86. The research done by Veck and Bill (2000) and Thomas and Syme (1988) offers a better comparison for the current study area. The method approach in these two studies is also directly comparable, including the range of the price increased. In addition, different income levels of income were also considered in both studies. For the total water usage, the elasticity of demand are almost identical, i.e. –0.18 in Australia and –0.17 in Alberton/Thokoza.

The high price elasticity of demand for the lower income group and the very inelastic demand for the upper and middle income groups can be contributed to the unique situation in South Africa. The situation is such that the middle and high income groups have very high incomes compared with the lower income combined with the fact that the water tariffs are so low. Overall, the elasticity for the high and middle income group is –0.35 and for the lower income group –1.12.

8.4.6 Aggregation of Demand Schedules

To arrive at the aggregated demand schedule for each income group, the populations of appropriate magisterial districts were utilized for the Groot Letaba, Klein and Middle Letaba as well as the transfers-out to capture the total water consumption of the Letaba Catchment area. The appropriate magisterial districts were as follows:

- Groot Letaba: Included in this Catchment area are Giyani and Tzaneen,
- Klein and Middle Letaba: Included in this catchment area are the Greater Letaba District and the Tribal Authorities in the area,
- Transfers-Out: Included is Polokwane.

The population's household trend is given for the year 2001 (Census 2001). A scenario was formulated whereby household trends in the relevant magisterial districts for 2002 were determined using a calculated growth rate and are summarised in Table 8-7 below for the total Letaba Catchment area:

TABLE 8-7: TOTAL NUMBER OF HOUSEHOLDS FOR THE TOTAL CATCHMENT AREA, 2002, BY INCOME LEVELS

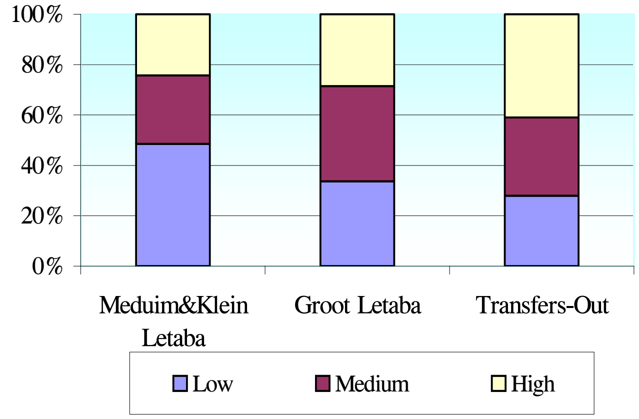
	Total Letaba	Catchment	Area	
		Income	Level	
District	**Low**	**Medium**	**High**	**Total**
Greater L	25 071	3 215	7 406	35 692
TA's	16 886	-	-	16 886
Giyani	24 534	2 ,667	9 570	36 771
Tzaneen	39 965	5 394	16 115	61 475
Polokwane	79 145	17 500	37 357	134 002
Total Households	**185 601**	**28 777**	**70 448**	**284 825**

The following conclusions can be drawn to the total number of households in this Catchment Area:

- The number of households in the low income group in this study area is the largest and accounts for 65% of the municipal users.
- The number of households in the medium income group is the smallest, and accounts for 10% of the municipal users. The total water consumption of this group varies from 3 million to 4 million on an annual basis.
- The number of households in the high income group accounts for 25% of the municipal users, and the total water consumption varies from 8 million to 11 million on an annual basis.

This structure is presented for different income levels, by sub-catchment, in Table 8-5 below:

FIGURE 8-5: PERCENTAGE STRUCTURE TO HOUSEHOLDS IN THE LETABA CATCHMENT AREA PER SUB-CATCHMENT, 2002



From the above figure it is evident that the low income group is the most representative in the Letaba Catchment Area. Using this structure together with the total water consumption per income group as detailed in Table 8-8, the derivation of the aggregated demand schedule can be undertaken.

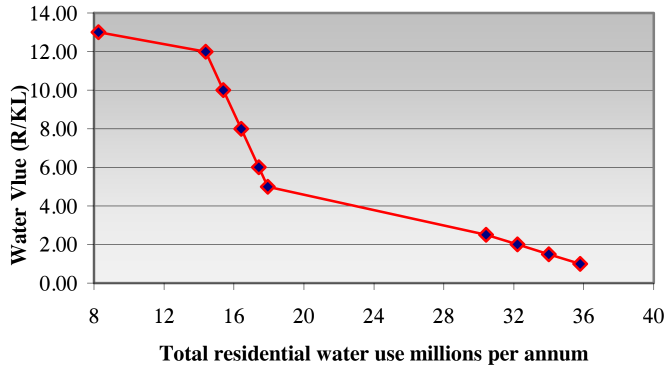
TABLE 8-8: WATER CONSUMPTION PER INCOME GROUP 2002 [KILOLITRES, MILLIONS]

	High income	Medium income	Low income	Total
Medium & Klein Letaba	8.42	0.46	2.49	11.36
Groot Letaba	9.80	1.56	2.92	14.28
Transfers-Out	3.25	1.20	6.14	10.59
Total	**21.47**	**3.22**	**11.55**	**36.24**

Figure 8.6 below presents the aggregated demand schedule for total municipal water use in the catchment in graphical form. The quantities demanded represent the total water used per annum and are in units of a million kiloliters,

and the prices indicated represent the average water tariff. The current total municipal water use in the study area is 36 million kiloliters per annum, and this is represented by the right-hand side of the schedule.

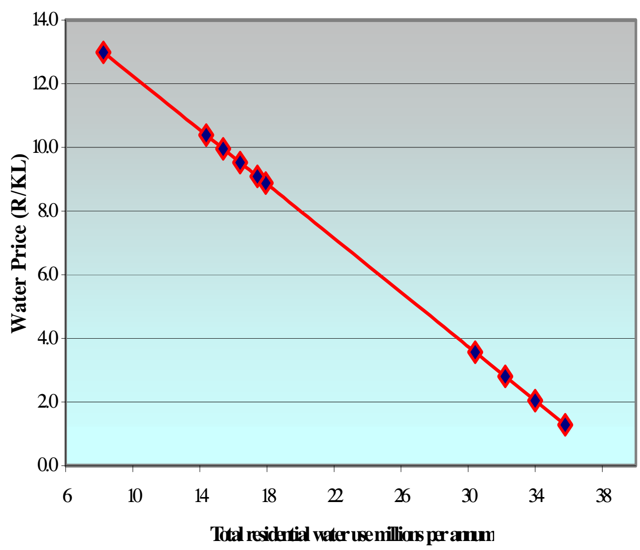
FIGURE 8-6: AGGREGATED DEMAND SCHEDULE: TOTAL LETABA CATCHMENT, TOTAL MUNICIPAL WATER USE, M^3- MILLIONS



Elasticity	-0.205

To use this aggregated demand curve in the NSP model, the schedule should be linearised. The linear regression of the aggregated demand schedule is presented in Figure 8-7 below.

FIGURE 8-7: AGGREGATED DEMAND SCHEDULE: TOTAL LETABA CATCHMENT, TOTAL HOUSEHOLDS [LINEAR REGRESSION]



This linearised aggregated demand schedule is utilized as input into the integrating (NSP) model for municipal water consumption. Quantities are presented in millions of cubic metres per annum and prices represent the average price for water. The total calculated consumer surplus for total municipal water, before taking costs into account, is calculated to be R79,70 million. However, in order to compute the actual economic value the costs of providing municipal water have to be brought into the equation as well, as discussed in the next section.

8.5 COSTS

8.5.1 Introduction

The water demand schedules developed in the above sections reflect municipal water users' willingness-to-pay for water and embody the costs of water as well as its intrinsic value. To arrive at the intrinsic value of water, it is necessary to evaluate the costs associated with its provision and to subtract these from the values derived above.

Value and costs have been kept separate throughout the exercise in order to facilitate later presentation of the information to the integrating model (the NSP model) for scenario evaluation.

In this section appropriate cost schedules will be developed.

8.5.2 Cost of Municipal Water in the Letaba Catchment Area

Cost associated with the provision of water in the Letaba Catchment vary with regard to the specific income group and geographical area. The cost structures of municipal water in the areas chosen to stand as proxy for the different income groups are:

- costs in the low income group are based on a flat-rate structure; and
- costs in the high and middle income group are based on a quantity-based tariff with rising blocks.

The calculation of costs starts with the costs to DWAF of supplying bulk water. It should be noted that these costs are not the same as the DWAF bulk supply tariff which does not reflect all the costs. To this must be added costs to municipalities for purifying and reticulating water. The difference between the DWAF bulk tariff (which does not reflect DWAF costs) and the municipal tariff is taken to be representative of the municipal purification and reticulation costs. In this way total costs are equal to DWAF costs plus municipal costs.

The elements that are necessary to calculate total costs for the three income groups are summarised in the Table 8-9 below.

TABLE 8-9: AVERAGE COSTS ASSOCIATED WITH MUNICIPAL WATER IN THE LETABA CATCHMENT AREA [CENTS PER M^3, 2002/03]

Income Level	DWAF Costs	DWAF Tariff	Municipal Tariff
High	25.88	8.69	462
Middle	25.88	8.69	428
Low	270.6	57.39	100

In this table the costs and tariffs per income level are as supplied by the Department of Water Affairs and Forestry, and municipal tariffs are those in force in the municipalities concerned.

It will be seen that a significant proportion of the delivery costs are associated with the low income group compared to the middle and high income groups.

Stemming from the information in Table 8-9, the estimated average costs associated with the provision of water to each income level are presented in Table 8-10 below.

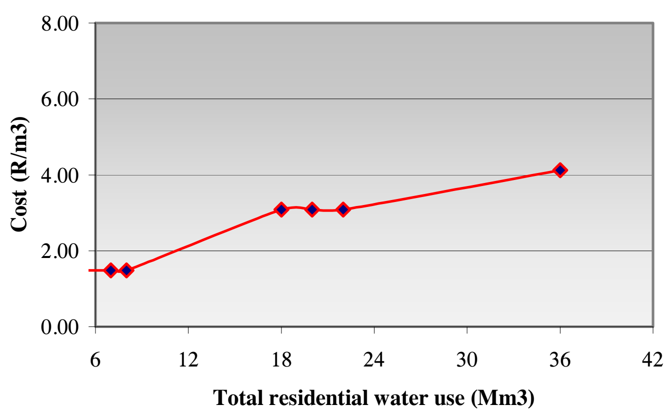
TABLE 8-10: ESTIMATED AVERAGE COSTS FOR THE PROVISION OF MUNICIPAL WATER IN THE STUDY AREA[RAND PER M^3]

Income Level	High	Middle	Low
Costs	4,79	4,46	3,13

Figure 8-8 below shows the aggregated cost curve for municipal water use for the whole catchment.

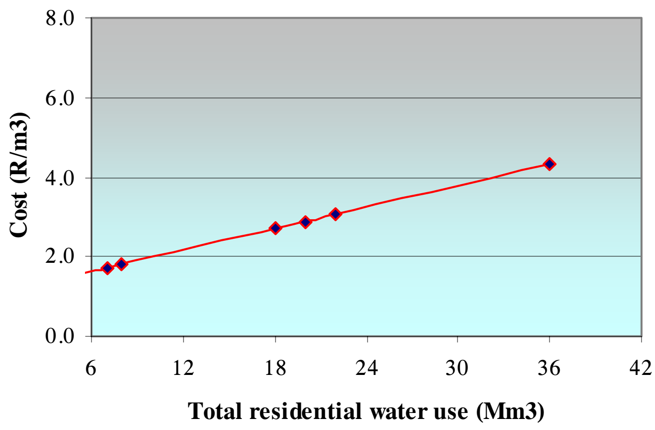
In a manner analogous to the aggregation of the water demand curves, the aggregated cost curve was derived using the costs from Table 8.10, taking into account the costs of providing water for each of the income levels at each level of total water use.

FIGURE 8-8: COST SCHEDULE FOR MUNICIPAL WATER IN THE LETABA CATCHMENT AREA



To utilise the above cost schedule in the NSP model, it is linearised by regression analysis. The resulting linear cost schedule is presented in Figure 8-9 below.

FIGURE 8-9: COST SCHEDULE FOR RESIDENTIAL WATER IN THE LETABA CATCHMENT AREA - [LINEAR REGRESSION]



The above linear regression cost schedule for municipal water demand reflects the flat rate structure for the low income group as well as the quantitative-based cost structure for the high and middle income group.

8.6 COMPARISON OF COST AND VALUE

8.6.1 Introduction

This section draws on the methodology used in the "Net Social Payoff" (NSP) model used as an integrating model in Chapter 10. The value estimated for municipal water and the costs associated with its provision are brought together, thereby arriving at the intrinsic value of municipal water.

8.6.2 Costs vs. Value

The concepts of value, price and tariff are often used interchangeably in economic discourses, thereby creating unnecessary confusion. These terms are not synonymous and Tewari (2003) has summed the situation up as follows:

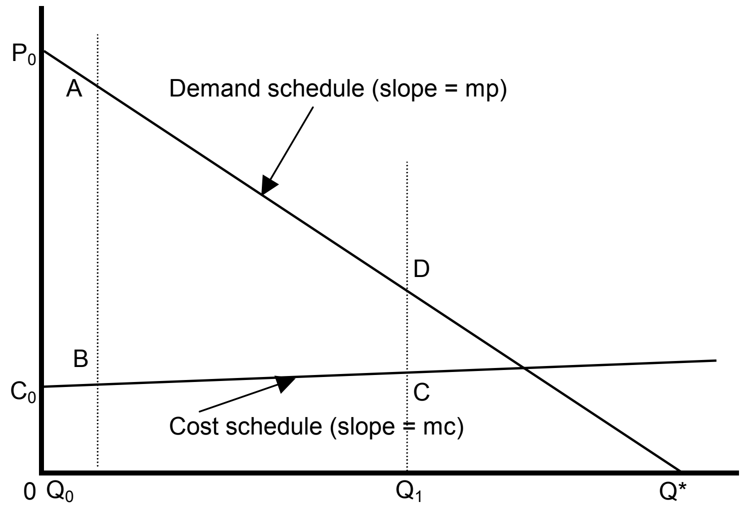
"The term "value" refers to the expected net benefits from the resource; it is hence [a] purely conceptual definition and has no direct relation with the market. The term "price" refers to a market-determined value which arises after a consensus between a willing buyer and a willing seller is reached. The term "tariff" refers to the cost recovered boy the government or water agency in order to provide this service …"

As there is no formal water market, we have no price as defined above, only tariffs, and value can be thought of in terms of the tariff users are willing to support in order use any given quantity of water. The demand schedules developed in the foregoing sections of this chapter are based on this concept and a contingent valuation survey was used to uncover consumers' willingness to pay for water. As such, these demand schedules are a reflection of the value of water.

Taking the economic value of water and subtracting the costs of the water to arrive at the efficiency of water use. From an empirical measurement perspective, total value of water for municipal use can be revealed by the consumer's surplus (area under the demand curve but above the water price/marginal utility)

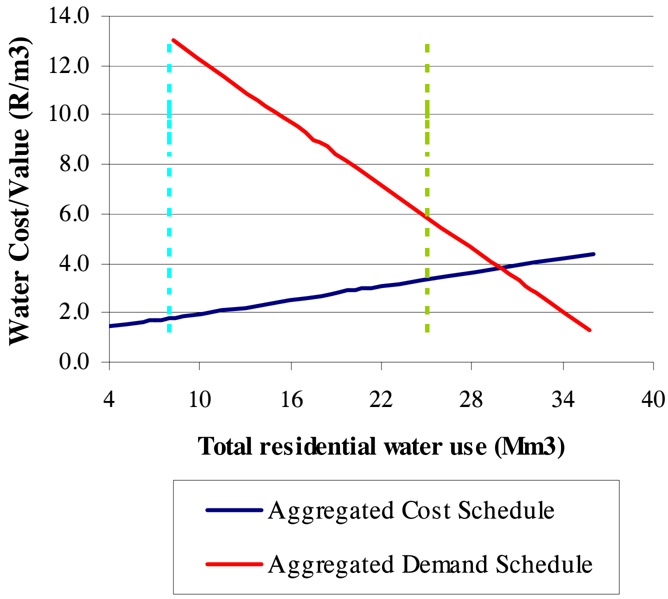
The theoretical framework for the comparison of the cost and value is graphically represented in Figure 8-10 and 8-11 below. Cost and demand schedules are both depicted linearly, as this is the form in which they will later be presented to the NSP model.

FIGURE 8-10: THEORETICAL REPRESENTATION OF COST VS. VALUE



From the graph above, the consumer's surplus is reflected by the quadrilateral ABCD. The quantity Q_0 is the "human reserve" or quantity of water to be provided to all at no cost. The quantity Q_1 is the level of supply for which the value of water is being determined. The total utility accruing to a user at this level is represented in monetary terms by the area Q_0ADQ_1. The revenue generated by the transaction is given by the area Q_0BCQ_1. The area BADC therefore represents additional utility or "surplus" which has accrued to the user. This arises because the consumer has obtained all his water at the price associated with point C, and has not paid for each individual unit of water at its marginal rate.

FIGURE 8-11: WATER DEMAND AND COST SCHEDULES FOR THE LETABA CATCHMENT AREA



These results can be used for analysis in the economic consequences of allocating and pricing water at different levels in municipal uses in the Letaba Catchment Area/ System.

Figure 8-11 above (which is the same as Figure 8.10, but embodies the actual values calculated for the total Letaba Catchment) graphically represents the cost and demand schedules for total municipal water use. It is important to note that this aggregated demand schedule represents a weighted average of high and low income earners, and is subject to some distortion due to:

- the fact that some users are subject to flat-rate tariffs (not linked to usage) which encourages excessive usage of water, and which disguises true willingness-to-pay in CV surveys; and
- the fact that average is lowered where there is significant non-payment for water.

The following are the key issues revealed by the diagram:

- The lower limit, which emerged from the CV Experiment is a total municipal water usage of 8 million m^3. The upper limit, which is the current water usage (DWAF, 2003), is 25,35 million m^3. The area between the upper and the lower limit and the cost and demand schedules, forms a quadrilateral, which is the intrinsic value of water. This value is calculated at R283.72 million.
- The market clearing point for water usage is 30 million kilolitres at an R4,00 price. One can see from the figure that the current water usage is 25 million m^3. The reason why the current usage does not occur at the market clearing point is that water is a non-market good and not driven by market sources, but subject to institutional control. Figure

8.12 demonstrates that the current consumption is less, and the value higher, than would have been the case if a free water market was in place.

8.7 CONCLUSION

The CVM in this study, utilizing the one-pass approach, has proved to be an effective approach for determining the economic value of municipal water. Comparisons made between the results of this study and previous studies locally and internationally give confidence in both the methodology and the results. Although the calculation of price elasticities of demand for water do not form and intrinsic part of this study, elasticities are simple to derive from demand schedules, and they form a convenient way of comparing results with other studies. Some comparisons are presented in Table 8-11 and Table 8-12 below.

TABLE 8-11: COMPARISON OF PRICE ELASTICITIES FOR TOTAL WATER USAGE

Researcher/s	Date	Type of Analysis & Location	Elasticity
International			
Thomas and Syme	1979	Contingency Valuation Perth Australia	-0.18
Local			
Veck & Bill	1998	Contingency Valuation South Africa	-0.17
Current Study	2003	Contingency Valuation South Africa- Letaba Catchment Area	-0.21

TABLE 8-12: COMPARISON OF PRICE ELASTICITIES FOR WATER USAGE PER INCOME GROUP

	Low Income	Middle Income	High Income
Current Study	-0.39	-0.25	-0.29
Tshwane	-0.37	-0.17	-0.12
Cape Town	-0.11	-0.101	-0.09
eThekweni	-0.13	-0.134	-0.14

Source: van Vuuren et al.

The price elasticities estimated in this study will be seen to be consistent with those produced by other studies. In all cases these are arc elasticities, in other words they are calculated using a chord between two points on the demand curve. Care needs therefore to be taken when interpreting elasticities since the results depend upon the length of the chord use, and its position on the demand curve. In terms of the above comparison, consistency exists in the sign of the value of elasticity (they are all negative) and they are all of the same order of magnitude. The price elasticity for the middle and high income group in this study tend to be higher than those in Tshwane, Cape Town and eThekweni. A possible reason for this is that no "human reserve", or free allowance, is included in Polokwane's tariff structure, and this could impact on consumers' behaviour. In the scenarios, to follow in chapter 10, allowance has been made for a "human reserve".

Furthermore, the data in the CV Survey for this study reveals no outliners which significantly influence the results. The derived demand schedules are consistent with economic theory. The range of values in the demand schedules are summarised in Table 8.13 below:

TABLE 8-13: SUMMARY OF RANGES OF VALUES IN DEMAND SCHEDULES (CENTS/KL)

	Contingent Valuation Survey			**Aggregated demand**
	Low Income	**Middle Income**	**High Income**	**Total**
Lower bound [kℓ per month for average household]	34	44	52	8 million kℓ
Upper Bound [kℓ per month for average household]	47	54	66	36 million kℓ
Current Tariff [Rand per kiloliter]	1,00	5,32	5,59	-
Consumer Surplus/Economic value	65.79	352.45	462.80	79.7 million

The cost pertaining to municipal water, using the linearised demand and costs schedules, which constitute suitable input to the NSP model, will be compared and discussed in detail in Chapter 10 of this study.

9 ECOLOGICAL WATER

9.1 BACKGROUND AND OBJECTIVE

Much work has been done in past years on the environmental health aspect of rivers. The concept of the Environmental reserve has been developed to promote the ecological integrity of rivers, estuaries, wetlands and groundwater resources. Although the actual determination of the reserve in a number of rivers has been carried out scientifically, in most of the river basins it is still very much based on scientific informed opinion.

However, in South Africa, which is a water scarce country, it may eventually become necessary to justify the allocation of water to the ecology by demonstrating the benefits to the ecology of the river and environment maintained by this allocated water and estimating its value. The setting of the reserve in certain locations could generate opposition from current beneficiaries, who may be required in some cases to reduce or limit their abstraction levels, thereby resulting in direct costs to these beneficiaries.

A further factor is that at present water users have little information regarding the benefits and value of services provided by aquatic ecosystems. Also, relatively few users are able to indicate the value of their use of water and have very little knowledge of the cost of this use to other users. Consequently there is a clear need to develop a framework to quantify and value services, and identify the full range of beneficiaries.

It is important to note that human activities are not separate from the ecology of rivers. Humans use goods and services that create impacts that influence ecological function, structure of habitats and, on perhaps a larger scale, regional processes. The implication is that while the river has the potential to supply goods and services to communities, the range and yield of goods and services are dependant on how much it is allowed to function naturally.

In the case of the Letaba basin the water balance performed for this project has very clearly showed that if the balance is done with the MAR, there is still a reserve left. But if compared with the yield, it is obvious that at times of low flow the river ecological system must be under severe stress. In this section of the study the purpose is to determine the economic value of the water allocated to the ecological reserve and compare it to the other sectors investigated.

9.2 RATIONALE AND METHODOLOGY

Whilst in the other sectors the value of the water to its users outside the river was determined, in the case of the ecology water the value of the water will be determined while it remains in the river. The Letaba enters and runs through the world renowned Kruger National Park and it was therefore decided to calculate the value of the water both outside the park and the value inside the park. Using this approach also makes it possible to use two different methods and compare the results attained.

Inside the Park it was decided to use a methodology based on the tourism potential of a river using the surplus concept and outside the park based on the benefits accruing to the local population arising from the presence of the water in the river.

9.3 ECONOMIC VALUE OF ECOLOGY WATER

In the following sections the economic value of ecology water is determined and described in two parts:

- the economic value inside the Kruger National Park; and
- the economic value outside the Kruger National Park.

9.3.1 Economic Value of Ecology Water: Inside Kruger National Park

This section is a desktop evaluation of the ecology reserve in the park and is based on a report of the Institute of Natural Resource, University of Natal[3]. The study leader was Jane Turpie and the research was done for the Institute of National Resources – University of Natal in association with the Percy Fitzpatrick Institute – University of Cape Town, the Department of Statistical Sciences – University of Cape Town, and the University of Stellenbosch.

Within the KNP, current tourism value was considered in terms of (a) revenues to KNP, or visitors' on-site expenditure, (b) contribution to the economy, or visitors' on-site and off-site expenditure, and (c) recreational value, including consumers' surplus – which is visitors' willingness to pay over and above actual on- and off-site expenditure. These values were apportioned to different parts of Kruger, *viz*. the Komati Basin, Letaba Basin, etc.

The following extract from this report comments upon the authors' methodology in their own words:

> "All three measures are potentially valid, but they differ in terms of who benefits or receives the value. While both measures of expenditure reflect proven willingness to pay, consumer surplus reflects additional, theoretical willingness to pay. On-site expenditure reflects the benefits to the protected area authority, but total expenditure reflects the benefits to the economy as a whole. In both of these cases, there is a knock-on effect called the multiplier effect, in which these expenditure lead to further spending in other sectors of the economy. However, we have not attempted to measure this value here.
>
> On-site expenditure is the easiest to measure and to understand. The measurement of total expenditure attributable to a resource is rarely applied and is based on a

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[3] Incorporating Economic consideration into the determination of the Environmental Reserve - Case Study: The tourism value of river in and adjacent to Kruger National Park, and impacts of a change in river quality – 2001.

subjective assessment by the users. As long as questions aimed at eliciting these assessments are well phrased so as to be properly understood by the respondents, this measure can be considered relatively accurate. In this study, respondents did not appear to have a problem with this concept. Recreational use value is the total value or willingness to pay for the enjoyment of an amenity. Strictly speaking, it thus comprises consumer surplus as well as expenditure. Consumer surplus is most commonly estimated by means of the Travel Cost method (Bockstael et al., 1991; Tobias & Mendelssohn, 1991; Dobbs, 1993; Freeman, 1993; Navrud & Mungatana, 1994). This method is favoured where on-site expenditure ill-reflects the value of an amenity due to low or zero entry costs. Where prices reflect market value, the estimation of consumer surplus is less critical to valuation and decision-making. In this study, although we accounted for the problem of multiple site visits by eliciting the amount of total trip expenditure attributable to KNP, we still arrived at an extremely high estimate of consumer surplus in the order of R1.4 billion. Interestingly, this value is almost three times as high as the estimated US$203 million consumer surplus for all of Kenya's national parks. For several reasons, we feel that consumer surplus should not be considered in the reserve determination process:

1. Consumer surplus is a difficult concept for most stakeholders and decision-makers to digest;
2. The result obtained may vary considerably depending on the way in which origin zones are grouped; and
3. Other socio-economic factors such as income and consequent differential spending power in different zones should be taken into consideration, making the method even more complex."

The issue of consumer surplus is an economic concept which many people do not accept, because they very often do not understand the willingness-to-pay concept and its concomitant assumptions. However, from an economic and mathematical viewpoint the methodology is finding wide-spread acceptance. The methodology and mathematics in the quoted report has been reviewed by the project team who are of the opinion that it is sound and it has therefore been decided to quote the results from all three methodologies in the report for comparison purposes. These are set forth in Table 9-1.

TABLE 9-1: CALCULATION OF VISITOR EXPENDITURE ATTRIBUTABLE TO THE LETABA AREA WITHIN KNP, (2001)

	On-site expenditure	On-site and off-site expenditure	Consumer Surplus
Whole of Kruger	R135 793 193	R266 626 926	R1 127 250 000
Letaba Basin	R 10 736 000	R 21 081 000	R89 127 000
Value of water R/m³	0,10	0,20	0,85

These values must be compared to R1,09/m³ for agriculture, R0,27/m³ and R0,66/m³ for the two forestry species and the value of the municipal water of R2,22/m³. As discussed in the chapter about Municipal water, the consumer surplus and contingent valuation methodologies are generally accepted and in this case the value of R0,85/m³ is within the range of the values obtained for other sectors.

9.3.2 Economic Value of Ecology Water: Outside Kruger National Park

As already stated human activity interacts with the ecological system. One interaction is the physical activity of removing the water from the river and using it in different activities. The value of the water when used thus has already been calculated; in this section the purpose is to quantify the economic impacts of the water that remains in the river outside of the KNP. The matrix designated Table 9-2 gives an indication of the services and functions of an ecosystem.

When examining this process, it is clear that decision making regarding the use of any river or the allocation of water and management resources between alternative uses takes place in a politico-economic context. Here the value of water remaining in rivers is compared with the value of abstraction for alternative uses. However, in most cases the value of rivers to society is expressed qualitatively, whilst the benefits of the alternative uses to which it can be put are usually explicit and quantifiable. The lack of quantifiable packages with regard to river ecosystem services, and a clear understanding of the river service users, precludes the ready identification of stakeholders and the valuation of these services. This results in rivers being undervalued and frequently inappropriate decision-making regarding their use and management.

A focus on riparian and in-stream services provides decision makers with a clearer understanding of the uses and benefits of rivers and therefore can help to inform the trade-offs which are likely to be made in determining water allocation.

Importantly, a single process may supply more than one service, and similarly a service may be dependent on several processes. As some ecosystems perform many ecological functions simultaneously, they have the characteristics of joint production. Ecosystem services also have the characteristics of public goods. These characteristics have significant implications for the way ecological assessments are made. Joint production of public goods implies the need to integrate research around key service issues, rather than key components of the river system.

TABLE 9-2 RIVER ECOSYSTEM SERVICES AND FUNCTIONS (AFTER COSTANZA ET AL., 1997)

Ecosystem Services	Ecosystem Functions	Examples
Gas regulation	Regulation of chemical composition of the atmosphere	Carbon sequestration, oxygen and ozone production
Climate regulation	Regulation of temperatures, precipitation at local levels	Urban heat amelioration, wind generation
Disturbance regulation	Regulation of episodic and large environmental fluctuations on ecosystem functioning.	Flood control, drought recovery, refuges from pollution events
Water supply and regulation	Supply and regulation of water flow	Provision of water for agricultural, industrial and household use (spatially and temporally)
Sediment supply and regulation	Regulation of sediment supply to river, estuary and marine environment	Maintenance of beaches, sand bars, sand banks.
Erosion control	Retention of soil within an ecosystem	Prevention of soil loss by vegetation cover, and by capturing soil in wetlands
Soil formation	Soil formation processes.	Weathering of rock by water and accumulation of organic material in wetlands and floodplains
Nutrient cycling	Storage, recycling, capture and processing of nutrients	Nitrogen fixation, nitrogen cycling through food chains
Waste treatment	Recovery of nutrients, removal and breakdown of excess nutrients	Breaking down of waste, detoxifying pollution
Biological control	Regulation of animal and plant populations	Predator control of prey species, disease control
Refugia	Habitat for resident and migratory populations	Nurseries, habitat for migratory fish and birds, regional habitats for species
Food production	Primary production for food	Production of fish and plants
Raw materials	Primary production for raw materials	Production of craftwork material, house building materials and fodder
Genetic resources	Unique biological materials and products	Genes for food, ornamental species, plant fibres and medicinal products
Nature appreciation	Providing opportunities for the appreciation of natural features and wildlife	Providing access to features and wildlife for viewing and walking
Sport fishing	Provision of opportunities for sport fishing	Flyfishing and conventional fishing
Water sports	Provision of opportunities for sport in water	Swimming, Sailing, canoeing, skiing, white water rafting
Scenic view	Provision of scenic views	Residential houses, flats and offices with scenic views.
Transport	Provision of opportunities for water based transport	Harbours, ferries, ski-boat launching
Cultural	Providing opportunities for non-commercial uses.	Aesthetic, educational, spiritual, intrinsic and scientific values of ecosystems.

A range of techniques can be used to derive estimates of the values of these services. The important question is when can these services be added together and when must they be considered as substitutes? In order to address this, the following approach was followed in terms of service election:

i) A decision is made on the nature of the services provided by the ecological resources. For example, are they separable and independent sources of value, or does the increase in one service affect the marginal value of the other? For the estimates of the values of various services to be additive, the services must be separable. It is also important to identify those components of value that cannot be estimated due to theoretical or data problems.
ii) The critical assumptions underlying the valuation of each service are made, and it is determined what kind of estimate results from the method being used. In particular it is important to determine whether the value is marginal, average or total and whether it is an upper-bound or lower-bound estimate.
iii) When values are being transferred from other studies, the protocols that make such transfer of values possible are observed.

After considering the above and consultation in the catchment, it was decided to concentrate on the following services and to quantify them.

- Fishing (food processing)
- Thatch grass
- Reeds
- Recreational fishing
- Recreational Boating
- Recreational swimming
- Waste accumulation
- Waste dilution
- Cultivated floodplains
- Provision of household water
- Provision of stock water

The following possible costs to the population were considered and treated as disbenefits:

- Bilharzia
- Crocodile incidents
- Hippo incidents

At this juncture it needs to made clear that there is an enormous choice of possible services and disbenefits which could be used in carrying out the analysis. It would lie beyond the scope of this report to undertake an exhaustive analysis: the intention is to provide and test, within a suite of models, an approach which could be effective and useful in determining the value of ecological water.

The list above was therefore selected by the research team, after consultation with specialists in the area, as being one that would provide an appropriate cross-section of inputs to the model.

Many other factors were considered before deciding on the above list. These include activities such as bird-watching, fly-fishing and boating. Similarly, there are other disbenefits including diseases such as malaria and cholera which could have been included.

For each of these services, seen as benefits or disbenefits (possible costs), a range of quantifying parameters and assumptions was developed. It must be emphasised that this was mostly based on a general study of the Letaba catchment, and the validity of the amounts can be improved with a considerable in-depth, on-site investigation. In the next section the results are represented followed by a detail discussion on each individual service, benefit and disbenefits.

9.3.3 Results

In Table 9-3 below, the individual results of each service, benefit and disbenefit are presented.

TABLE 9-3: VALUE OF ECOLOGY WATER IN THE GREAT LETABA CATCHMENT - SERVICES AS BENEFITS VS. DISSERVICES AS COSTS [RANDS, 2003 PRICES]

Services	Annual Value [Rands, 2003 Prices]	Value of Ecology Water [Rand per m3]	Percentage Contribution of Services
Services as Benefits			
Food Production			
Fish	1 194 891	0.0130	5.39%
Raw Material			
Thatch grass	330 750	0.0036	1.49%
Reeds	145 800	0.0016	0.66%
Recreational activities			
Fishing	1 027 858	0.0112	4.64%
Boating	1 557 360	0.0169	7.02%
Swimming	339 588	0.0037	1.53%
Waste Treatment			
Waste assimilation	1 438 089	0.0156	6.49%
Waste Dilution	9 463 018	0.1029	42.68%
Water Supply & Regulation			
Cultivated Floodplains	2 880 000	0.0313	12.99%
Provision of Stock Water	1 293 515	0.0141	5.83%
Provision of Household Water	2 499 732	0.0272	11.27%
Total Benefits	**22 170 601**	**0.2410**	**100%**
Disservices as Costs			
Bilharzia	5 980 755	0.0650	99.8%
Crocodiles	5 119	0.0001	0.1%
Hippos	7 678	0.0001	0.1%
Total Disbenefits	**5 993 552**	**0.0651**	**100%**
Gross Benefit	**16 177 049**	**0.1758**	

Note: Water used for the maintenance of the ecology: 92 million m^3

9.3.4 Assumptions and Parameters

Although the length of the Great Letaba is generally accepted to be 120 km outside the Kruger, the Middle and Klein has to be added with all the tributaries. Eventually it was decided to use 360 km as the total length of the river banks.

The detailed different parameters used for each of the different benefits and disbenefits are highlighted in the Annexures included in Appendix 4. In the following sections the results of each service are presented.

9.3.4.1 Food Processing: Fishing

Table 9-4 presents an estimation of the benefits to the community in the form of edible fish caught in the Letaba River.

TABLE 9-4 BENEFITS ACCRUING TO THE COMMUNITY FROM FISHING

Number of households within Impacted area	Participation rate of Households	Annual fish consumed per Household kg	Total Annual fish consumed kg	Annual Value Rand/kg
13 830	60%	12	99 574	1 194 891

The estimated benefit due to edible fish caught is R1.2 million per annum. In order to determine this benefit, the major assumption was to calculate the number of households within the impacted area. The number of households impacted, 13 830, was arrived at by taking the area of the river affected (see Appendix 4, Annexure 9A) multiplied by a calculated rural population density rate. Further, it is assumed that the population density is higher near rivers due to the attraction of water. The result, the total population of the impacted area, 72 606, divided by the average number of individuals per household, confers the number of households within impacted area. Another parameter was to assume that only 60% of these households is catching fish for edible purposes. Further it is assumed that the annual fish consumed per households is 12 kg per annum with an economic value of R12 per kg.

9.3.4.2 Raw Materials: Thatch Grass

In Table 9-5 is an estimation of the benefit to the community from cultivation on the thatch grass.

TABLE 9-5: BENEFITS TO THE COMMUNITY FROM HARVESTING THATCH GRASS.

Annual Thatch Grass Harvested (kg/ha)	Usage Factor for Impacted Area	Impacted Area (ha)	Price per Thatch Grass (Rand/kg)	Annual Value (Rand)
1 500	70%	900	2,80	330 750

To measure the impact of thatch grass on the annual value of water, the impacted area was calculated and additional parameters were used too. The impacted area consists of the length of the Letaba River as well as the width of the impacted area that is estimated in a percentage of the river affected.

The parameters that were used, are also shown in the table above and include the annual thatch grass harvested (kg/ha), the usage factor for the impacted area and the price per thatch grass (Rand/kg). It is assumed that there will be an annual use of thatch grass, and that the life span of the thatch grass is eight years. By incorporated the above elements, the annual value of thatch grass in Rand per kilogram is in the range of R2,80/kg and the total annual value R0.33 million. The full calculation will be found as Appendix 4, Annexure 9B.

9.3.4.3 Raw Materials: Reeds

Table 9-6 is an estimation of the value of the reeds growing along the river and utilised by the rural community.

TABLE 9-6: BENEFITS ACCRUING TO THE COMMUNITY OF THE REEDS CUT ALONG THE RIVER BANKS.

Annual Reeds Harvested (kg/ha)	Usage factor for Impacted Area	Impacted Area (ha)	Price Per Reeds (Rand/kg)	Annual Value Rand/kg
600	30%	540	12	145 800

To measure the impact of reeds on the annual value of water, the impacted area was calculated and additional parameters were used too. The impacted area consists of the length of the Letaba River as well as the width of the impacted area that is estimated in a percentage of the river affected.

The parameters that was used, is also shown in the table above and include the annual reeds harvested (kg/ha), the usage factor for the impacted area and the price per reeds (Rand/kg). It is assumed that there will be an annual crop of reeds, and the replacement life span of the reeds is eight years. By incorporating the above elements, the annual value of reeds in Rand per kilogram is R12 and the total annual value is R0.146 million. The full calculation will be found as Appendix 4, Annexure 9C.

Recreational Fishing

Table 9-7 is an estimation of the value of the recreational fishing taking place along the river .

TABLE 9-7: THE VALUE OF THE ANNUAL RECREATION FISHING TAKING PLACE ALONG THE RIVER

Number of individuals fishing per day	Percentage fishing in the Impacted Area	Number of Days fishing per annum	Daily Fishing Tariff Rands	Annual Value Rands
93	60%	112	165	1 027 858

The main assumption in the estimation of the value of recreational fishing is the determination of the average number of individuals in the recreational area, i.e. holiday resorts. To establish this number, statistics relating to the Eiland resort (with 103 chalets with an average of 4 individuals per unit) were used, and these were assumed to be representative of the whole region. Taking into consideration only high seasonal fishing (112 days per annum) with a daily value per individual of R165,00, it is assumed that only 15% of the individuals in the recreational area are fishing along the river. A full calculation will be found as Annexure 9D.

9.3.4.5 Recreational Boating

Table 9-8 is an estimation of the value of the recreational boating taking place along the river.

TABLE 9-8: THE VALUE OF THE ANNUAL RECREATION BOATING TAKING PLACE ALONG THE RIVER

Number of individuals fishing per day	Percentage Boating in the Impacted Area	Number of Days Boating per annum	Daily Boating Tariff Rands	Annual Value Rands
93	75%	112	200	1 557 360

The main assumptions to estimate the value of recreational boating is to determine the average number of individuals in the recreational area, i.e. holiday resorts. Again, the statistics relating to the Eiland were taken to be representative of the area. Taking into consideration only high seasonal boating (112 days per annum) with a daily value per individual of R200,00, it is assumed that only 15% of the individuals in the recreational area are boating along the river. A full calculation will be found as Annexure 9E.

9.3.4.6 Recreational Swimming

Table 9-9 is an estimation of the value of the recreational swimming taking place along the river.

TABLE 9-9: THE VALUE OF THE ANNUAL RECREATION SWIMMING PLACE

Number of individuals swimming per day	Percentage Swimming in the Impacted Area	Number of Days Swimming per annum	Daily Swimming Tariff Rands	Annual Value Rands
210	75%	112	19	339 588

The main assumptions to estimate the value of recreational swimming is to determine the average number of individuals in the recreational area, i.e. holiday resorts. Again, the statistics relating to the Eiland were taken to be representative of the area. Taking into consideration only high seasonal boating (102 days per annum) with a daily value per individual of R19,00. This daily value represents the average recreational value per individual swimming for 2 hours. Further it is assumed that only 34% of the individuals in the recreational area are swimming along the river. A full calculation will be found as Annexure 9F.

9.3.4.7 Waste Treatment: Waste Assimilation

Table 9-10 presents a estimation of the benefit to the community in terms of waste assimilation by the river water.

TABLE 9-10: BENEFITS ACCRUING TO THE COMMUNITY BECAUSE OF WASTE ASSIMILATION FUNCTION OF THE RIVER WATER.

Number of households within Impacted area	Benefit Coefficient	Annual Value Rand
20 745	69.32	1 438 089

The estimated benefit due to waste assimilation is R1.44 million per annum. In order to determine this benefit, the major assumption was to calculate the number of households within the impacted area and the benefit coefficients. The number of households impacted, 20 745, was arrived by taking the area of the river affected (see Annexure 9J) multiplied by a calculated rural population density rate. Further, is assumed that the population density is higher near rivers due to the attraction of water. The result, the total population of the impacted area (161 347) divided by the average number of individuals per household, confers the number of households within the impacted area. Another parameter was to assume the benefit coefficient for waste assimilation taken from the Thukela River Study.

9.3.4.8 Waste Treatment: Waste Dilution

Table 9-11 presents an estimation of the benefit to the community in terms of waste assimilation by the river water.

TABLE 9-11: BENEFITS ACCRUING TO THE COMMUNITY BECAUSE OF THE WASTE DILUTION FUNCTION OF THE RIVER WATER

Number of households within Impacted area	Benefit Coefficient	Annual Value Rand, 2003 Prices
20 745	456.17	9 463 018

From the table above, it can be concluded that the estimated benefit due to waste dilution is R9.45 million per annum. To determine this benefit, the major assumption was to calculate the number of households within the impacted area and the benefit coefficients. The number of households impacted, 20 745, was arrived at by taking the area of the river affected (see Annexure 9K) multiplied with a calculated rural population density rate. Further, it is assumed that the population density is higher near rivers due to the attraction of water. The result, the total population of the impacted area (161 347) divided by the average number of individuals per household confers the number of households within impacted area. Another parameter was to assume the benefit coefficient for waste dilution taken from the Thukela River Study.

9.3.4.9 Water Supply and Regulation: Cultivated Floodplains

Table 9-12 is an estimation of the benefit to the community from cultivation on the floodplain.

TABLE 9-12: THE VALUE OF THE BENEFIT TO THE COMMUNITY FROM CULTIVATING ON THE FLOODPLAINS.

Impacted Area (per hectare)	Percentage of River Impacted by Floodplains	Annual Gross Margin (tons per hectare)	Usage rate of Impacted Area	Annual Value Rands
180 000	2%	1 000	80%	2 880 000

The benefit to the community from cultivating on the floodplains is R2,8 million. The methodology followed to determine the benefit was firstly to determine the impacted area (see Annexure 9L) in hectares. It is assumed that of this area floodplains only occur in 2% of the total impacted area. Further it is assumed that 80% of these floodplains are used to harvest crops, mostly maize, with a gross margin per annum of R1 000 per hectare.

9.3.4.10 Water Supply and Regulation: Provision of Household Water

Table 9-13 is an estimation of the value of the provision of household water along the river in the rural community.

TABLE 9-13: THE VALUE OF THE PROVISION OF HOUSEHOLD WATER

Number of Households Within Impacted Area	Participation rate of Households	Annual Usage per Household [m^3]	Willingness to Pay [Raw water] [m^3]	Annual Value (Rand)
10 372	70%	64	5.39	2 498 731

The estimated benefit due to the provision of household water R2.5 million per annum. In order to determine this benefit, the major assumption was to calculate the number of households within the impacted area. The number of households impacted, 10 372, was arrived by taking the area of the river affected (see Annexure 9N) multiplied with a calculated rural population density rate. Further it is assumed that the population density is higher near rivers due to the attraction of water. The result, the total population of the impacted area (72 606) divided by the average number of individuals per household confers the number of households within impacted area. Another parameter was to assume that only 70% of these households are consuming the water for household purposes. Further is it assumed that the per capita water usage per day is 25 m^3 with a value of raw water in rural areas of R5,39/m^3. The value of R5,39/m^3 was calculated following the method recommended in A Manuel for Cost Benefit Analysis in South Africa ,WRC report No. TT 172/02, to calculate the value of water for rural people.

Economic value of water = (4% of actual monthly house hold income) divided by (monthly water consumption per house hold)

Economic value of water =(4% of R715) divided by (25*30.5*7/1000)

The R715 /month average income per household comes from the data supplied by the Demarcation Board (2001) in compiling the social profile of the three district municipalities operating in the area namely Greater Letaba, Greater Giyani and Greater Tzaneen. It is interesting to note that according to the above mentioned data base, the number of households stating that they use the river as water source is 10 944, which is very close to the number of 10 372 calculated using the above methodology.

The 4% is recommended by the Development Bank of Southern Africa as the upper limit to be spend by rural people on water at 25l per person per day.

9.3.4.11 Water Supply and Regulation: Provision of Stock Water

In Table 9-14 is an estimation of the value of the provision of stock water along the river in the rural community. A full calculation will be found as Annexure 9M.

TABLE 9-14: THE VALUE OF THE PROVISION OF STOCK WATER

Number of LSU Within Impacted Area	Annual Water Use by Livestock (m^3)	Usage Factor by Livestock	Price per unit [R/kg]	Annual Value
22 050	563 378	70%	3.28	1 293 515

The value of R1.3 million represents the benefit for the water usage of the livestock within the impacted area. The major assumption in determining the benefit due to the provision of stock water is the livestock numbers within the impacted area. The approach followed was to determine the number of Large Stock Units (LSU) using the weight and grazing needs of one LSU defined as a 450 kg beast. The number of LSU is determined by the impacted area in hectares divided by the carrying capacity, i.e. the required hectare per LSU to arrive at the number of LSU. Further it is assumed that only 70% of the livestock uses the water from the river at 70l/day per LSU.

The value of the livestock water was then calculated by using the method proposed in the CBA Manual for the private portion of rural water consumption.

The value of livestock water = (value of social portion + existing tariff) /2

The value of livestock water = (R5,29/kl +R1,18/kl)/2

= R3,29/kl

9.3.4.12 Disbenefits: Bilharzia

In Table 9-15 is an estimation of the value of the Bilharzia in the river and affected by the rural community. A full calculation will be found as Annexure 9H.

TABLE 9-15: DISBENEFITS TO THE COMMUNITY OF BILHARZIA IN THE LETABA RIVER.

Number of Individuals Infected	Household Infection Rate	Annual Cost (Rands)
10 372	15%	5 980 775

To measure the impact of Bilharzia on the annual value of water, the impacted area, the population density of the river, population density of the impacted area and the number of individuals infected in the impacted area. There were also additional parameters of the population and the total cost calculated.

The impacted area consists of the length of the Letaba River as well as the width of the impacted area that is estimated in a percentage of the river affected. The population is calculated by dividing the total population adjusted by a population growth figure in 2002 with the area (km^2). The population of the impacted area is estimated by multiplying the population of the total area, the percentage of the river affected and a deviation factor from average rate of population density. The estimated number of individuals infected in the impacted area was determine by using an awareness rate of Bilharzia that is in total 1 556 individuals affected. It was assumed that the productivity loss per bilharzia incident is 10% which converted to R3 644 per incident . To this was added R200 per case medical cost to give a total of R3 844 per incident. The total cost of bilharzia to the community was calculated to be R5.98 million per annum.

9.3.4.13 Disbenefits: Crocodile Incidents

Table 9-16 is an estimation of the cost of the Crocodile incidents in the river as it affects the rural community. A full calculation will be found as Annexure 9G.

TABLE 9-16: DISBENEFITS TO THE COMMUNITY OF CROCODILE INCIDENTS IN THE LETABA RIVER.

Number of Incidents Within Affected Area per Year	Productivity loss rate	Annual Cost (Rands)
1	6%	5 119

Parameters that were used of crocodile incidents included the number of incidents in affected area per annum, number of casualties per year, number of days hospitalised, capitalised economic value of persons, value of work time per day, that is R13,71 per hour, estimated by the average value of population, and daily medical cost per day. The total cost was then calculated by the above parameters. By multiplying the number of incidents in affected area per annum (1 individual) by the total cost per incident is equal to the annual cost of crocodile incidents of R5 119.

9.3.4.14 Disbenefits: Hippo Incidents

In Table 9-17 is an estimation of the value of the Hippo incidents in the river and affected by the rural community. A full calculation will be found as Annexure 9I.

TABLE 9-17: DISBENEFITS TO THE COMMUNITY OF HIPPO INCIDENTS IN THE LETABA RIVER.

Number of Incidents Within Affected Area per Year	Productivity Loss Rate	Annual Cost (Rands)
1	10%	7 678

Parameters that were used for hippo incidents included the number of incidents in affected area per annum, number of casualties per year, number of days hospitalised, capitalised economic value of persons, value of work time per day, that is R13,71 per hour, estimated by the average value of population, and daily medical cost per day . The total cost was then calculated by the above parameters. By multiplying the number of incidents in affected area per annum (1 individual) by the total cost per incident is equal to the annual cost of hippo incidents of R7 678.

It can be argued that hippo incidents can also be beneficial, due to their activities in the river, and this could also be taken into account in a more exhaustive study.

9.4 CONCLUSION AND RECOMMENDATIONS

In this chapter two methodologies to calculate the value of the ecology component of water in the Letaba basin were discussed. In the first instance the value was determined inside the Kruger National Park by using the tourism value of the water in the river as a point of departure. This was based on research done by the Institute of National Research, University of Natal; the values obtained are not out of range and in our opinion reasonable. It must however be stated that the research values used were biased towards the Sabie and Crocodile rivers.

In the second instance, a survey was performed to give values to goods and serviced delivered to the community but it must be emphasised that this was not an in-depth survey. Despite this, the results attained are not out of line with the values obtained for other sectors. An improvement in accuracy could be obtained by conducting a CV survey, similar to that described in Chapter 8 or along the lines set out by Hosking (2002). Hosking provides a framework for conducting such a survey and he obtains an environmental opportunity cost of abstracting water from the Keurbooms River at R0,046/m^3/annum. This is rather lower than the figure obtained in this study, and quoted below.

TABLE 9-18: VALUE OF ECOLOGY WATER IN THE GREAT LETABA CATCHMENT: SERVICES AS BENEFITS VS. DISSERVICES AS COSTS [RANDS, 2002 PRICES]

Services	Annual Value [Rands, 2002 Prices]	Value of Ecology Water [Rand per m^3]
Services as Benefits	**20 975 709**	**0,228**
Food Production	1 194 891	0,013
Raw Material	467 550	0,005
Recreational activities	2 924 805	0,032
Waste Treatment	10 901 107	0,118
Water Supply	6 673 247	0,073
Disservices as Costs	**6 673 247**	**0,067**
Bilharzia	5 980 755	0,065
Crocodiles	5 119	0,001
Hippo's	778	0,001
Gross Benefit	**14 982 156**	**0,163**

The final estimate of the value of ecological water taking into account all the products and services discussed, is given in Table 9-18. It must however be stressed that water values estimated by both methodologies can be improved by an in-depth study in the area, such as, perhaps along the lines suggested by Hosking (2002). What this study has illustrated is that both methodologies have merit and that values obtained are credible if compared with other sectors, but even more important is the fact that economic tools are now available to assess the economic value of rivers.

In the context of this overall study, it also needs to be emphasised that the differing methodologies used for calculating the value of water when put to different uses means that results are not necessarily directly comparable. Particularly, not all values are marginal values. Care therefore needs to be taken in the interpretation of results before direct comparisons are made.

10 SCENARIOS AND THE NSP MODEL

10.1 INTRODUCTION

In this chapter results obtained in the previous chapters dealing with the value of water will be brought together and compared. Furthermore, the supply and demand schedules which were developed will be used in a model to re-allocate water according the principle of maximisation of social welfare. The specific methodology outlined in Chapter 3 will be more fully described.

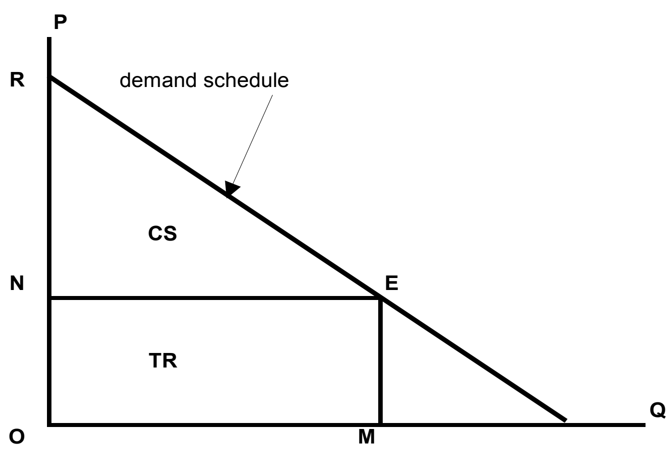
The basis for the model used is an intersectoral equilibrium optimisation procedure wherein the allocation and pricing of regulated water supplies are such that the economic value of this water in its multiple use regime is maximised.

This will have the effect of bringing together the demand and cost schedules developed for various water users in an integrating model which allocates water according to the principle of maximisation of social welfare. The model achieves this end by calculating the consumer's surplus associated with each water demand schedule and using linear programming to reallocate water in such a way as to maximise the sum of the individual consumer's surpluses, thereby maximising social welfare, or Net Social Payoff (NSP), as it is referred to by Samuelson (1961).

10.2 THE CONSUMER'S SURPLUS AND NET SOCIAL PAYOFF

Where money constitutes a realistic measure of utility, there consumer's surplus can be readily measured and depicted. Referring to Figure 10-1 below, an idealised demand curve is presented by PQ. When consumers buy OM goods at ON price, they pay the total revenue (TR) represented by the area OMEN; but that quantity of goods gives them a total utility (expressed in money terms) represented by the area OMER. The additional area NER represents their consumer's surplus (CS).

FIGURE 10-1: THE CONSUMER'S SURPLUS



Samuelson (1980) observes:

> ”Each unit of a good that the consumer buys costs him only as much as the last unit is worth. But by our fundamental law of diminishing marginal utility, the earlier units are worth more to him than the last. Therefore, he enjoys a surplus on each of these earlier units. When trade stops benefiting and giving him a surplus, he stops buying.”;

and further goes on to comment:

> “The fact that market price is determined by marginal rather than total utility is dramatized by the concept of consumer’s surplus. Since we pay in the market for each unit the same price that the marginal unit is worth to us, we reap a consumer’s surplus on all the previous units. This consumer’s surplus reflects the benefit we gain from being able to buy at low prices, rather than being confronted by a ruthless monopolist who insists we pay him for the whole of our consumption just what that total is worth to us.”

This area representing the consumer’s surplus has also been called the Net social Profit (or Net Social Payoff) (Samuelson, 1952). This arises from the fact that the concept of a consumer’s surplus can be used to assist in making correct social decisions.

10.3 THE MODEL

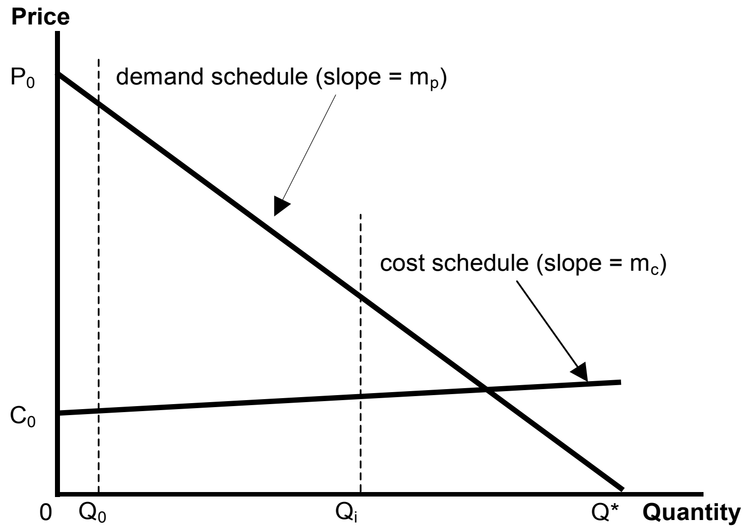
These concepts provide the essential underpinning of a model to re-allocate water. The object of the model being allocation, the underlying principle is to optimise the allocation of water by maximising specific objectives. Such optimising exercises are handled effectively by linear programming (LP). The problem was formulated in the form of an objective function and a set of constraints which could be presented to a linear programming solver. The approach chosen was to set out the problem in MicroSoft Excel and use What’s Best! as the LP solver.

The actual formulation of the problem is best illustrated by considering diagram embodied in Figure 10-2 below. The NSP for each water-use category is represented by the area bounded by the demand and cost schedules and the water quantity constraints Q_0 and Q_1, as described in Chapter 3, Section 3.3.5.

The equation specifies the aggregate of all the NSPs and also represents the objective function in the linear programme. This objective function is derived by considering the areas representing the NSPs of the individual water using sectors and summing these in the form of a mathematical equation. The form of the objective function given in Figure 10-2 is the final , simplified version; the complete derivation of the formula is given in Appendix 1.

When the linear programme is exercised, an upper limit of the water allocation Q1 is determined for each water use sector, and the optimum water allocation is calculated by the LP, subject to the requirement that the total water allocated may not exceed the total available supply. In addition, the value of the NSP is calculated, to be used as a bench-mark against which the goodness of any one scenario can be evaluated vis-à-vis any other. Figure 10-3 depicts the LP tableau which generated statistics for the current water supply four water using sectors.

FIGURE 10-2: ESSENTIALS OF THE NSP MODEL



$$NSP = \sum_{i=1}^{n} \left[(P_{0i} - C_{0i}) * (Q_i - Q_{0i}) + (mp_i/2 - mc_i/2) * (Q_i^2 - Q_{0i}^2) \right]$$

	P0	mp	Q*	C0	mc	Q0
Agriculture	3.494314	-0.016744	208.685	0.109	0	63.18
Pine	0.831046	-0.011520	72.139	0.0098	0	7.60
Gum	0.458646	-0.008746	52.441	0.0098	0	3.44
Residential	16.500000	-0.425079	38.816	1.068441	0.090799	6.00
Ecology	0.190000	0.000000	n/a	0	0	0.00

$$NSP = \sum_{i=1}^{n} [(P0i - C0i) * (Qi - Q0i) + (mpi/2 - mci/2) * (Qi2 - Q0i2)]$$

	P0-C0	Qi-Q0	mp/2-mc/2	Qi2-Q02	
Agriculture	3.3853141	87.7	-0.008372	18781.55	139.740
Pine	0.8212458	7.2	-0.005760	160.38	4.965
Gum	0.4488458	18.1	-0.004373	450.96	6.139
Residential	15.431559	19.4	-0.257939	606.62	142.129
Ecology	0.19	92.00	0	8464.00	17.480
				NSP benchmark	***310.454***

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	150.91	=<=	150.91
Pine	7.60	<=	14.77	=<=	14.77
Gum	3.44	<=	21.51	=<=	21.51
Residential	6.00	<=	25.35	=<=	25.35
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.54	=<=	304.54

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	150.91	0.97	1.59
Pine	14.77	0.66	0.69
Gum	21.51	0.27	0.34
Residential	25.35	5.72	7.35
Ecology	92.00	0.19	0.19
		weighted average	***1.38***

FIGURE 10-3: LINEAR PROGRAMMING TABLEAU DEPICTING THE CURRENT WATER ALLOCATION

10.4 SCENARIO GENERATION

The following categories of scenario have been suggested by members of the Steering Committee:

- intersectoral water reallocations
- changes in the level of total water available; this could include the use of underutilised water as well as seasonal changes in water availability.

The NSP model was exercised to verify that its handling of variations to its inputs such as suggested above and the results are presented below.

The value of Ecological water has also been incorporated into the model, although as a single value, since no demand schedule was determined.

In the scenarios below, a certain allocation of water is postulated by adjusting the constraints on water available to each sector. The NSP model then generates the optimum allocation of water according to the principle of maximisation of social welfare. In addition it calculates the price at which the water should be sold, and its value, based upon the Net Social Profit calculated by the model for that specific water allocation. (It must be pointed out that the price is simply the price at which social welfare would be maximised; it is intended that this should provide guidance for water managers, and is not suggested that this should represent any future tariff). It should be noted that this price is an average of the total quantity of water taken. Similarly, the value as calculated by the model is the value of the consumer's surplus, or NSP, associated with the amount water taken at the stated price. This is an average value for all the water taken, excluding all costs, and as such represents the intrinsic value of the water itself.

The generation of each scenario is based upon a tableau such as is illustrated in Table 10-3. The full tableaux are not presented for each scenario, but in the discussion that follows, the inputs which are presented to the model are given, the output from the model is presented, and the results are interpreted. These issues will be dealt with in detail during the discussion of the first scenario; in succeeding scenarios they will simply be identified and any differences from the description given for Scenario 1 will be highlighted.

10.5 SCENARIO 1: CURRENT CONSUMPTION

10.5.1 Method

The desired allocation criteria for water are set by manipulating the constraints presented in the tableau below. Adjusting the upper limit controls the maximum allocation of water allowed in any sector. Adjusting the lower limit sets the minimum allocation which will be given to each sector. Qi is one of the outputs of the NSP model and this indicates the allocation which has been made by the model. In this scenario it is desired to force the allocation to the present usage. This is a trivial problem in terms of allocation, but it is done to obtain and NSP benchmark.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	150.91	=<=	150.91	=<=	150.91
Pine	14.77	=<=	14.77	=<=	14.77
Gum	21.51	=<=	21.51	=<=	21.51
Municipal	25.35	=<=	25.35	=<=	25.35
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.54	=<=	304.54

It will be seen that the upper and lower limits were set the same, at the current usage, and the model has delivered the same allocations (Q_i).

Further results obtained are as follows:

NSP benchmark **310.45**

This benchmark as discussed above, characterises the particular water allocation with which it is associated, in terms of maximisation of Net Social Profit. It represents, in money terms, an average of the sum of all the consumer's surpluses generated by this allocation. It does not indicate whether the allocation is optimum or not, but it does provide a benchmark against which other allocations can be judged. If any other allocation produces a higher NSP benchmark, then it has been more effective at optimising NSP; If it is lower, then it was less effective.

The model also uses this figure to generate the economic value of water in each user sector, and this is set out in the tableau below, and discussed in Section 10.5.2.

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	150.91	0,97	1,59
Pine	14.77	0,66	0,69
Gum	21.51	0,27	0,34
Municipal	25.35	5,72	7,35
Ecology	92.00	0,19	0,19
		weighted average	***1,38***

10.5.2 Interpretation of Results

The Value of Water Tableau above contains three elements:

- The quantity of water allocated to each sector by the model in terms of the maximisation of NSP;
- The price, as determined by the demand schedules calculated in previous chapters, for each quantity of water; and
- The value of water as calculated by the NSP model. This represents a value per unit quantity of water which the user receives in terms of utility, but is not reflected in the price they pay – it is the intrinsic value of the water itself.

It should be noted that the prices set out above are not the water tariffs, they are the prices reflected in the relevant demand curves for the quantities of water taken. These prices reflect the users' willingness to pay.

The value, as already stated, is the value of additional utility received but not paid for. This arises from the fact that all water is paid for at the marginal price of the last unit supplied – each unit is not priced at its marginal price. This value provides a measure of the intrinsic worth to its user of the quantity used.

The following scenarios will explore the impact of different allocations of water. These scenarios will both test the workings of the NSP model, and at the same time probe the boundaries of feasibility with respect to allocation and reallocation of water. As such two areas will be explored, *viz*. reallocation of the present total usage between sectors and use of additional unused water that could arise from water conservation efforts, loss control and development of additional water resources. I should be noted that although ecology water is represented in the model, in order that it may make a contribution to the NSP benchmark, it cannot be reallocated since no demand schedule for ecological water was developed, and hence no consumer's surplus can be calculated for this use.

10.6 SCENARIO 2: CURRENT CONSUMPTION OPTIMISED

10.6.1 Method

Scenario 1 forced water allocation to its current level; the object was to calculate a value for NSP, and not attempt to reallocate water. It is now necessary to see whether, given a freer hand, the model can reallocate water and achieve a higher NSP. This scenario will explore that possibility. To achieve this, the upper constraints are kept the same as Scenario 1, but the lower constraints are relaxed to allow reallocation of water away from any sector. This is demonstrated n the constraints tableau below.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	150.91	=<=	150.91
Pine	7.60	<=	14.77	=<=	14.77
Gum	3.44	<=	21.51	=<=	21.51
Municipal	6.00	<=	25.35	=<=	25.35
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.54	=<=	304.54

It will be seen that the model has not reallocated any water, as shown by Q_1 above.

Further results obtained are as follows:

NSP benchmark **310.45**

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	150.91	0,97	1,59
Pine	14.77	0,66	0,69
Gum	21.51	0,27	0,34
Municipal	25.35	5,72	7,35
Ecology	92.00	0,19	0,19
		weighted average	***1,38***

10.6.2 Interpretation of Results

It will be noted that neither the benchmark nor the value of water have changed vis-à-vis Scenario 1. This indicates that the current allocation using the current upper limits is in fact optimal. To reallocate water, or allocate new water, the upper constraints will have to be manipulated. This will be done in the succeeding scenarios.

10.7 SCENARIO 3: REALLOCATION OF WATER FROM AGRICULTURE TO MUNICIPAL

10.7.1 Method

In this scenario water was reallocated from agriculture to municipal use. To test the sensitivity of this transfer, amounts between 5 Mm^3 to 10 Mm^3 (some 3% up to 10% of current agricultural usage) were transferred. This was achieved by reducing the upper constraint on agriculture, and increasing the upper constraint on municipal in such a way that the total water used was not changed.

The outcome is shown in the constraints tableau below for the transfer of 5 Mm^3 of water. Within the range under consideration this amount of water provided the best NSP benchmark, and can be considered optimum.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	145.91	=<=	145.91
Pine	7.60	<=	14.77	=<=	14.77
Gum	3.44	<=	21.51	=<=	21.51
Municipal	6.00	<=	29.91	<=	30.35
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.10	<=	304.54

It will be seen that the upper and lower limits have been adjusted as discussed, and a water allocation Q1 has been generated. This allocation follows the selected upper constraints closely, and will be discussed below, under Interpretation.

Further results obtained are as follows:

NSP benchmark	**311.32**

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	145.91	1,05	1,63
Pine	14.77	0,66	0,69
Gum	21.51	0,27	0,34
Municipal	29.91	3,78	6,17
Ecology	92.00	0,19	0,19
		weighted average	***1,39***

10.7.2 Interpretation of Results

As was noted above, the allocation follows the upper constraints set, with the exception of municipal, where slightly less water has been allocated. This arises from the fact that at the amount of water allocated for municipal usage is at the clearing price, where the supply and demand schedules intercept. Any allocation in excess of this amount would have the effect of reducing the consumer's surplus.

The NSP benchmark has, however, increased slightly, indicating a more optimum allocation than is obtained in Scenario 2.

The overall value of water has risen very slightly, abut the individual prices and values have changed. The price and value for agriculture have risen, whilst those for municipal water have fallen. This is to be expected, as price is derived from the demand schedule, where price rises as quantity fall, and *vice versa*.

LP tableaux for all cases considered in this scenario will be found in Appendix 5.

10.8 SCENARIO 4: REALLOCATION OF WATER FROM AGRICULTURE TO FORESTRY

10.8.1 Method

In this scenario water was reallocated from agriculture to forestry. Allocation of water to forestry implies allowing forestry increased stream-flow reduction. To test the sensitivity of this transfer, amounts between 5% to 10% of current agricultural usage were transferred. The allocation to between pine and gum was done pro rat according to current consumption. This was achieved by reducing the upper constraint on agriculture, and increasing the upper constraint on pine and gum in such a way that the total water used was not changed.

The outcome is shown in the constraints tableau below for the transfer of 5% of agricultural water (7.5 Mm^3). Within the range under consideration this amount of water provided the best NSP benchmark, and can be considered optimum.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	143.41	=<=	143.41
Pine	7.60	<=	17.84	=<=	17.84
Gum	3.44	<=	25.94	=<=	25.94
Municipal	6.00	<=	25.35	<=	25.35
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.54	<=	304.54

It will be seen that the upper and lower limits have been adjusted as discussed, and a water allocation Q1 has been generated. This allocation follows the selected upper constraints exactly.

Further results obtained are as follows:

NSP benchmark **306.56**

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	143.41	1,09	1,66
Pine	17.84	0,63	0,67
Gum	25.94	0,23	0,32
Municipal	25.35	5,72	7,35
Ecology	92.00	0,19	0,19
		weighted average	***1,37***

10.8.2 Interpretation of Results

It will be noted that the allocation follows the upper constraints exactly.

It is also seen that the NSP benchmark has decreased vis-à-vis Scenario 2, indicating a less optimum allocation than is obtained in Scenario 2.

Again, vis-à-vis Scenario 2, the overall value of water has dropped very slightly, and the individual prices and values have changed. The price and value for agriculture have risen, whilst those for forestry water have fallen. As before, this is to be expected, as price is derived from the demand schedule, where price rises as quantity fall, and *vice versa*.

LP tableaux for all cases considered in this scenario will be found in Appendix 5.

10.9 Scenario 5: Reallocation of water from Forestry to Municipal

10.9.1 Method

In this scenario water was reallocated from forestry to municipal. To test the sensitivity of this transfer, amounts between 5% to 10% of current forestry usage were transferred. The reallocation from pine and gum was done pro rata according to current consumption. This was achieved by reducing the upper constraint on forestry, and increasing the upper constraint on municipal in such a way that the total water used was not changed.

The outcome is shown in the constraints tableau below for the transfer of 10% of forestry water (1.5 Mm^3 from pine and 2 Mm^3 from gum) to municipal. Within the range under consideration these amounts of water provided the best NSP benchmark, and can be considered optimum.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	150.91	=<=	150.91
Pine	7.60	<=	13.27	=<=	13.27
Gum	3.44	<=	19.51	=<=	19.51
Municipal	6.00	<=	28.85	<=	28.85
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.54	<=	304.54

It will be seen that the upper and lower limits have been adjusted as discussed, and a water allocation Q1 has been generated. This allocation follows the selected upper constraints exactly.

Further results obtained are as follows:

NSP benchmark	**314.01**

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	150.91	0,97	1,59
Pine	13.27	0,68	0,70
Gum	19.51	0,29	0,35
Municipal	28.85	4,24	6,44
Ecology	92.00	0,19	0,19
		weighted average	***1,40***

10.9.2 Interpretation of Results

As indicated above, allocation follows the upper constraints exactly.

It is also seen that the NSP benchmark has increased vis-à-vis Scenario 2, indicating a more optimum allocation than is obtained in Scenario 2.

Again, vis-à-vis Scenario 2, the overall value of water has risen very slightly, and the individual prices and values have changed. The price and value for forestry have risen, whilst those for municipal water have fallen. As before, this is to be expected, as price is derived from the demand schedule, where price rises as quantity fall, and *vice versa*.

LP tableaux for all cases considered in this scenario will be found in Appendix 5.

10.10 Scenario 6: Reallocation of Water from Agriculture to Forestry and Municipal

10.10.1 Method

In this scenario water was reallocated from forestry to municipal. To test the sensitivity of this transfer, amounts between 5% to 10% of agricultural usage were transferred. The reallocation to pine, gum and municipal was done pro rata according to current consumption. This was achieved by reducing the upper constraint on agriculture, and increasing the upper constraint on forestry and municipal in such a way that the total water used was not changed.

The outcome is shown in the constraints tableau below for the transfer of 5% of agricultural water (7.5 Mm^3) to forestry and municipal. Within the range under consideration these amounts of water provided the best NSP benchmark, and can be considered optimum.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	143.41	=<=	143.41
Pine	7.60	<=	16.57	=<=	16.57
Gum	3.44	<=	24.14	=<=	24.14
Municipal	6.00	<=	28.43	<=	28.43
Ecology	92.00	=<=	92.00	=<=	92.00
Total			304.54	<=	304.54

It will be seen that the upper and lower limits have been adjusted as discussed, and a water allocation Q1 has been generated. This allocation follows the selected upper constraints exactly.

Further results obtained are as follows:

NSP benchmark	310.15

Value of Water

	Quantity Mm³	Price R/m³	Value R/m³
Agriculture	143.41	1,09	1,66
Pine	16.57	0,64	0,68
Gum	24.14	0,25	0,33
Municipal	28.43	4,42	6,55
Ecology	92.00	0,19	0,19
		weighted average	***1,38***

10.10.2 Interpretation of Results

Allocation follows the upper constraints exactly.

It is also seen that the NSP benchmark has decreased slightly vis-à-vis Scenario 2, indicating a less optimum allocation than is obtained in Scenario 2.

Vis-à-vis Scenario 2, the overall value of water has remained the same, but the individual prices and values have changed. The price and value for forestry and municipal have fallen, whilst those for agriculture water have risen. As before, this is to be expected, as price is derived from the demand schedule, where price rises as quantity fall, and *vice versa*.

LP tableaux for all cases considered in this scenario will be found in Appendix 5.

10.11 SCENARIO 7: ALLOCATION OF UNUSED WATER

10.11.1 Method

In this scenario it was postulated that additional water would become available as a result of water demand management, loss control or development of additional resources, and that this would be allocated pro rata across all sectors. To test the sensitivity of this transfer, amounts between 5% to 15% of all water usage were allocated. This was achieved by increasing the upper constraint on all sectors, allowing total water to rise accordingly.

The constraints and resultant water allocation is shown in the constraints tableau below for the case of a 5% increase in allocation in each sector, except ecology. Since no demand schedule was calculated for ecology water, any change in allocation would affect neither its price nor the its value.

Constraints Tableau

	lower limit		Q_i		upper limit
Agriculture	63.18	<=	158.45	=<=	158.45
Pine	7.60	<=	15.51	=<=	15.51
Gum	3.44	<=	22.59	=<=	22.59
Municipal	6.00	<=	26.62	=<=	26.62
Ecology	92.00	=<=	92.00	=<=	92.00
Total			315.17	=<=	315.17

The impact of these action, together with the resultant NSP benchmark, prices and values are discussed in section 10.11.2 below.

NSP benchmark	**319.78**

Value of Water

	Quantity Mm^3	Price R/m^3	Value R/m^3
Agriculture	158.45	0,84	1,53
Pine	15.51	0,65	0,69
Gum	22.59	0,26	0,34
Municipal	26.62	5,19	7,02
Ecology	92.00	0,19	0,19
		weighted average	***1,36***

10.11.2 Interpretation of Results

Several comments arise from consideration of the results obtained in this scenario. The NSP benchmark rose vis-à-vis Scenario 2 for all cases considered. Up to the limits set for this scenario, all sectors except municipal were able to accept all water allocated, with an improvement in the NSP benchmark. As in Scenario 2, allocation to the municipal sector stopped when the price reached the market clearing price. In theory, all sectors could have accepted more water with an increase in NSP until each reached its market clearing price, but with the present demand and supply schedules this amount of water would have exceeded feasible limits. Furthermore prices and value would have continued to fall.

It must be remembered that the model is driven by a system of static demand and supply schedules which were constructed on the basis of the water usage pattern in place at the time. If variations in allocation are to be considered which depart too far from the current situation it would be necessary to review the demand and supply schedules. Particularly in the case of this scenario, the availability of additional water for allocation would be accompanied by increased costs, and hence different supply (and demand) schedules.

LP tableaux for all cases considered in this scenario will be found in Appendix 5.

10.12 CONCLUSION

The philosophy of maximisation of net social profit is one which has not been widely explored as a the basis for a model to allocate water. The intention in this chapter was therefore to present the underpinnings of the model and to use a selection of scenarios to indicate whether it could be feasibly used as an allocation mechanism. The selection of scenarios was done, therefore, with this aim in mind. The scenarios chosen are thus realistic, but were selected primarily as vehicles for exploring the NSP Model.

The model has proved able to allocate water according to the principle of maximisation of consumer's surplus (or NSP) and the results produced are consistent with realistic expectations. There are, however, some important issues and limitations surrounding the current implementation of the model.

Firstly, the major underpinning of the model are the demand and supply schedules which were developed during the earlier chapters of this research in the pursuit of the value of water in different sectors of the catchment. These schedules are by their very nature dependant upon the economic conditions in place at the time of the investigation, and they embody all the constraints upon demand and supply extant at the time. This does not preclude them from being used in a dynamic model, but it is important that the model is not used to examine situations which would give rise to significant changes in the demand and supply schedules. In other word, scenarios which depart too far from the current water usage pattern should not be used.

This fact has been underlined in the interpretation of Scenario 7, where additional water is allocated. Clearly the development of additional water resources, by whatever means, would have an impact on costs (supply schedules) and users' willingness-to-pay (demand schedules), and it was clear that to be used to explore substantial changes in allocation, both supply and demand schedules would have to be revisited.

The operation of a market clearing price in underpinning was also brought to light – the model would no longer allocate water once the quantity specified by the market clearing price in any sector had been reached. The implication was that at the market clearing price the allocation was most efficient – in other words, there should be no possibility for further in crease in consumer's surplus, and this principle has been highlighted by the model.

Finally, the demand and supply schedules which were used to test the model were both linear and highly aggregated. Considerable flexibility and accuracy could be introduced into the model by disaggregating the schedules and by de-linearising the resultant curves (either by transformation of the curves, or by synthesising them with a series of linear segments). Such considerations could form the basis for further research.

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 INTRODUCTION

This Chapter provides a summary of the objectives, result and conclusions of the study, and recommendations for future work are suggested.

11.2 SUMMARY OF OBJECTIVES AND RESULTS OF THE STUDY

The objectives of the study, as set out in Chapter 1 are to:

i determine the water balance in the catchment; taking into account the confluence of the Klein, Middle and Groot Letaba;
ii determine the water demand schedules for the irrigated agriculture, forestry, eco-systems and household sectors;
iii use these demand schedules to determine the economic value[4] of water by establishing willingness-to-pay;
iv determine the supply schedules for the same sectors in order to compare the cost of water with its value; and
v generate water use scenarios and evaluate their impact.

The hypotheses put forward are that:

i It is necessary to research the value of water because:
- water is scarce
- South Africa's water laws have recently changed, and
- knowledge of the value of water can assist with allocation decisions.

ii The value of water is embodied in the user's willingness to pay, which is revealed by the consumer surplus associated water demand schedules associated with different uses of water, where
- water demand may be direct (i.e. municipal and ecological usage), or
- derived (i.e. industrial, agricultural and forestry usage).

iii Water demand schedules can be synthesised using:
- contingent Valuation techniques for direct demand situations, and
- Linear Programming and Crop Production Functions for derived demand situations.

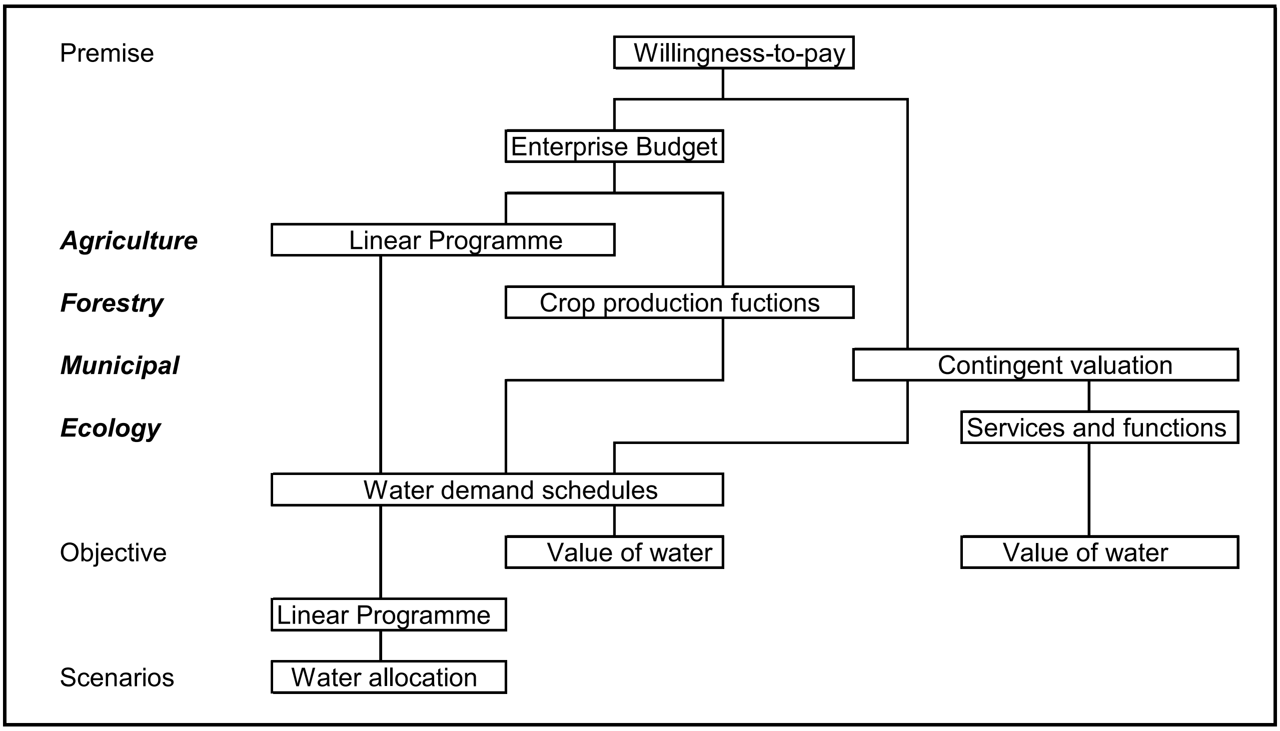
iv Water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques.

4 When we consider the value of water in this study, it is always the economic value which is being referred to. The economic value encompasses the complete value of water to the economy, not just the infrastructural costs associated with making water available to end users. In essence, it also incorporates the "value of the water drop"; the value of water itself as a commodity.

In seeking to meet these aims and objectives, and to prove the hypotheses, a method of modelling was postulated and several important results were produced. Although discussed extensively in earlier chapters, these will be briefly summarised here in order to bring the project to a conclusive conclusion.

11.3 MODELLING METHODS

In an attempt to bring the most appropriate methods into play in each of the water-using sectors, a multi-dimensional approach using a suite of models was employed. This is most effectively understood by considering the block diagram below.



Block Diagram of the modelling process.

The point of departure is that to calculate the economic value of water, the point of departure needs to be the economic principle of willingness-to-pay. The expression of this principal can be revealed both by examination of enterprise budgets and by carrying out contingent valuation surveys.

The main objective of the exercise is to develop the economic value of water but an important intermediate sub-objective is the synthesis of water demand schedules. Different methods were employed to achieve these objectives depending on the availability of appropriate data. The approach can be seen in the block diagram. The main objective was achieved for all sectors investigated but the intermediate objective of determining water demand schedules was achieved for agricultural, forestry and municipal water but not for ecological water as, in this case, it was only possible to gather information relating to willingness-to-pay for the current usage within the ambit of this project. Supply schedules, based on the cost of providing water, were also developed concurrently with the demand schedules.

The final objective, in which it was sought to integrate the disparate outputs from the different models, was to test the concept of allocating water according to economic principles by maximising consumer's surplus, and this was achieved using the Net Social Profit model.

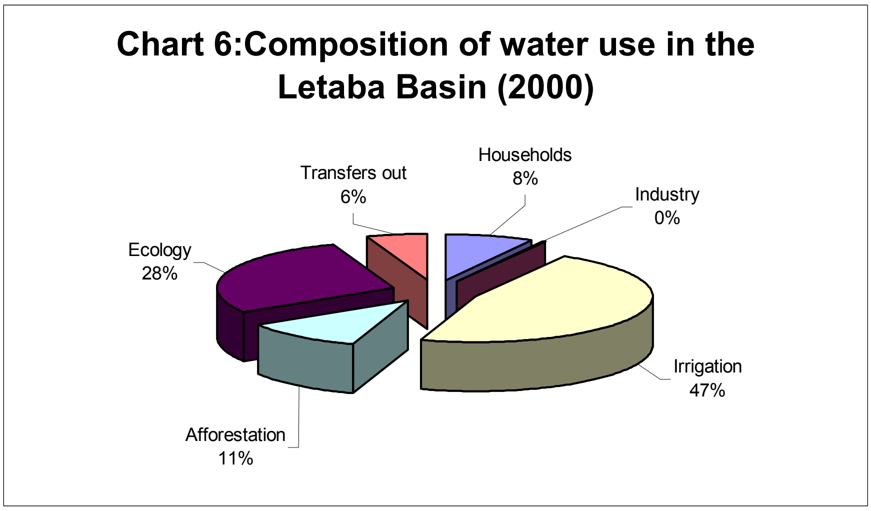
11.4 RESULTS

In this section there will be a brief reprise of the modelling methods used, together with a summary of the results thereby obtained.

11.4.1 Water Balance

The water balance was established by taking available water use data and compiling it into a system of water accounts. The pattern of water usage in place in the catchment at the time of the study, as revealed by these water accounts, is indicated most clearly in Chart 6 which appeared in Chapter 5 and is repeated below.

From this it can be seen that nearly 50% of the water is used for irrigation, with ecological use next at 28% and afforestation at 11%. It needs to be said that the assembly of data to compile these figures proved to be a difficult and time consuming task. Data sources proved to be sparse and frequently inconsistent. As an example, there was some confusion as to whether the transfers should have been set at 15 Mm3 (allocated) or 11 Mm3 (actual). It is also important to remember that much data was gathered in 2000 and the water balance situation is constantly in flux, on a seasonal as well as an annual basis. Care should therefore be exercised in placing too much reliance on these data. Having said that, however, they still provide the best basis available for providing the foundation for the calculation of aggregated water value for each sector.



11.4.2 Water Values and Costs

The approach to calculating the economic values of water was to develop demand schedules for water. These schedules show the economic price of water as revealed by the demand schedule, i.e. the price which would be current if there were a market for water. Thus at any quantity demanded, the price less the cost of providing would give the economic value of the water at that level of delivery. Several methodologies were used to derive the demand schedules, depending upon availability of data and appropriateness of the method. For agriculture farm budgets and linear programming were used, for forestry, enterprise budgets and timber production functions, and for municipal water, contingent valuation.

Table 11.1 which follows, brings together the water prices, costs and values which were revealed by the supply and demand schedules at the current level of usage. It must be borne in mind that the figures given relate only to the current levels of water use. As such they are not as revealing as the demand schedules, but they do provide a convenient means of comparison between the sectors. It should also be noted that these are the annual water values, not the capitalised values.

It will be seen that agriculture is the largest user of water and municipal the lowest. However, although the smallest user, municipal water has the highest value, followed by agriculture and then by forestry.

In terms of ecological water, as well as developing a water value by considering river products and services, the value of water when it reaches the Kruger Park is also calculated from studies done on the tourism value of water in the Kruger Park. Here it will be seen that the value of ecological water in the catchment is R0,19/m^3, but in the Kruger Park it can be as high as R0,85/m^3 when the consumer surplus is also taken into account.

TABLE 11-1: CURRENT WATER USAGE, VALUE AND COSTS

	Water Used Mm^3	Water Price R/m^3	Costs R/m^3	Water Value R/m^3
Agriculture	150.9	0,97	0,109	0,86
Forestry	36.3			
Pine	14.8	0,66	0,0083	0,65
Gum	21.5	0,27	0,0083	0,26
Municipal	25.4	5,72	3,5	2,22
Ecological	92.0	0,19	0	0,19
Kruger Park	92	0,85*	0	0,85

* includes consumer surplus.

The figures given above for agriculture and forestry are based on the enterprise budget approach to determining the value of water as discussed by Gibbons (1986). This approach postulates that any surplus in the enterprise budget could be a return to water, and thus represents the value of water. This could be contested on the basis that it represents a return to any of the factors of production, and overstates the value the value of water. Consequently these values could be seen as too generous. Nevertheless the approach does provide a yardstick which can be useful when allocating water, but this value must not be seen as a proxy for tariff.

Again it needs to be stated that difficulties with obtaining relevant data has been a great problem, and this is inevitably reflected in the accuracy of the calculations.

In the case of municipal water (mainly residential),the yardstick for calculating water value has been willingness to pay as revealed by contingent valuation. Again, this approach has its detractors, but Veck and Bill (2000) have concluded on the basis of their literature review that "[in contingent valuation methodology] considerable progress has been made in creating a tool that is useful for measuring non-market values".

Finally, because of the differences in approach to determining the value of water used in this study, care needs to be taken in making direct comparisons between findings in the different sectors. Nevertheless and integrating model was used to bring these findings together, and the implications are discussed in the next section.

11.4.3 Scenarios

Various water allocation scenarios were postulated to test the strength of the NSP model as an allocating mechanism. Three allocations will be presented, and their findings highlighted. The implications implicit in the findings will then be discussed.

11.4.3.1 Current Allocation (Status Quo)

This scenario examines the current water allocations. The table below gives details of the allocated quantities, together with prices, values and an allocation benchmark. The water price is the economic price as revealed by the water demand schedules at the given level of supply, but the water value is the value arising from consideration of the consumer's surplus accruing in the relevant sector as a result of taking the allocated water quantity. This approach takes effects of the price elasticity of demand into account and consequently the water value is much larger than the value derived in Section 11.4.2 above, being in each case larger rather than smaller than the price. The benchmark gives a measure of the total consumer's surplus associated with this scenario.

	Allocation Mm^3	Water Price R/m^3	Water Value R/m^3
Agriculture	150.9	0,97	1,59
Forestry			
Pine	14.8	0,66	0,69
Gum	21.5	0,27	0,34
Municipal	25.4	5,72	7,35
Ecological	92.0	0,19	0,19
		Benchmark	**310.45**

11.4.3.2 Scenario: Reallocate Agricultural to Municipal

This scenario examines the effect of reallocating 5 Mm^3 water from agriculture to municipal. The comments are the same as for the preceding scenario with the additional observation that the benchmark has increased over that associated with the status quo. This indicates a larger consumer's surplus and consequently a more effective allocation from the point of view of increasing social welfare.

	Allocation Mm^3	Water Price R/m^3	Water Value R/m^3
Agriculture	145.9	1,05	1,63
Forestry	36.3		
Pine	14.8	0,66	0,69
Gum	21.5	0,27	0,34
Municipal	29.9	3,76	6,17
Ecological	92.0	0,19	0,19
		Benchmark	**311,32**

11.4.3.3 Unallocated Water

This scenario examines the of allocating new and currently unused water. This situation could arise as a result of savings due to more effective demand management, better loss control, or development of new water resources. An increase of 5% in each sector is allowed for. Once again, comments are the same as for the preceding scenario, and it will be noted that prices have fallen and value has increased. The benchmark is the largest of the three scenarios.

	Allocation Mm^3	Water Price R/m^3	Water Value R/m^3
Agriculture	166.0	0,71	1,47
Forestry	36.3		0,68
Pine	16.2	0,64	0,68
Gum	23.7	0,25	0,33
Municipal	27.9	4,65	6,69
Ecological	92.0	0,19	0,19
		Benchmark	**327,30**

11.4.3.4 Implications

A hypothesis to be tested was that "water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques". This has been effected by subjecting the model to a series of scenarios designed to test its capabilities over a range of inputs, some of which are described above. It was found to allocate water effectively and consistently, according to the principle of maximisation of net social profit. This can be seen by the fact that the benchmark varies, and prices and values rise and fall in an appropriate manner. It was also found that the model would not allocate a greater quantity of water than that associated with the market clearing price which occurred at the intersection of the demand and supply schedules. This is due to the fact that the area of the consumer's surplus beyond the clearing price becomes negative, and including it reduces the overall consumer's surplus. This is consistent with the fact that economic theory holds that the market clearing price is the most economically efficient price. This means in practice that as the market clearing price for each sector reaches its clearing price, the rate of increase of the consumer's surplus would decrease, until such stage as all clearing prices have been passed, when no further increase in the consumer's surplus will occur. At this stage any further increases in allocation will not improve the benchmark. It should be noted that if this condition occurs, then it is likely that the supply and demand schedules are no longer relevant to these allocations, and the schedules should be revised.

It must again be emphasised that as the model stands the figures quoted are relative figures, covering a range of values with various levels of errors. The model should therefore be used to indicate broad trends only to guide policy formation and ought not to be used for detailed policy decisions. The use of the model will, however, indicate the direction which water markets might take if they could be implemented.

11.5 SUMMARY OF THE CONCLUSIONS

The literature surveyed gives support to our initial hypotheses and provides encouragement for proceeding with our chosen methodology. The literature on water accounts emphasises the need for proper water accounting to provide a sound basis for allocating water to various sectors. The use of Contingent

Valuation for valuing municipal water and the use of linear programming for deriving water demand schedules from enterprise budgets is also well supported.

Following the modelling approach outlined in the aims and objectives of the study, it proved possible to produce a suite of models which enabled water demand curves to be generated for the four water-using sectors covered by this study. In addition, means were provided to integrate these results and to explore and benchmark water-use scenarios by allocating water according to the principle of maximisation of net social payoff, used in this study as a proxy for social welfare.

This has effectively addressed hypotheses two to four stated in the introduction to this study, which state in essence that:

- water demand can be synthesised using contingent valuation techniques, linear programming and crop production function; and
- water allocation, according to the principle of maximisation of social welfare, can be effected by optimising the consumer surpluses that arise from all uses, using linear programming techniques.

As far as a consideration of the water balance is concerned (objective one), it proved possible to compile acceptable water resource accounts for the Letaba River Catchment. It should be noted that the emphasis was placed on the construction of the water balance framework and not other aspects of water resource accounting such as asset accounts.

The linear programming approach used in this study to develop water demand schedules for agricultural water use has provided schedules which are consistent with existing norms and which delivers results consistent with other exercises in this field. Some detail is lost in linearising the schedules but this is necessary in order to be able to present them to the NSP model and it also provides some smoothing of the intrinsically lumpy curves. The linear program was successful in deriving water demand schedules for individual crops as well as for aggregated agriculture.

Although great difficulty was experienced in obtaining suitable data for water production functions for forestry, the latest enterprise budgets (2002) were available from Forestry Economic Services and these budgets form the underpinning of the exercise. As in the case of agriculture, the water demand schedules have been linearised to enable them to be smoothed and carried forward into the NSP model.

The Contingent Valuation Survey in this study, utilizing the one-pass approach, proved to be an effective approach for determining the economic value of municipal water. Comparisons made between the results of this study and previous studies locally and internationally give confidence in both the methodology and the results. Furthermore, the data in the CV Survey for this study reveals no outliers which significantly influence the results. The derived demand schedules are consistent with economic theory.

In brief it can be said that the objectives of the study have been met, and that the hypotheses put forward have been proved.

However, as mentioned in the discussion above, some caution needs to be exercised when interpreting the results provided by this study. This comment need not detract from the value of the study, but it rather emphasises the need for understanding of the underlying principles and strengths and weaknesses of the models when using their results.

11.6 RECOMMENDATIONS

Having explored the various models discussed in this study and verified their operation, it is considered that much useful work could still be done in this field to remedy many of the shortcomings noted in the discussions. The following approaches are recommended:

- Attempts should be made to delinearise the linear programming models (including the agricultural and Net Social Profit models) by using non-linear objective functions.
- Adequate data sources are crucial for further research. Work should be done on identifying and assembling more accurate and appropriate data.
- The models do not necessarily need to be more robust – they have performed satisfactorily within their limitations in this study – but they would be more effective if used in a more focussed manner. This would mean using them on a more restricted data-set, where attention could be paid to improving accuracy in a more restricted environment.

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